(NASA-CR-143251) DETERMINATION OF FAILURE LIMITS FOR STERILIZABLE SOLID ROCKET MOTOR Final Report (Aerojet Solid Propulsion Co.) 75 p HC $4.25 CSCL 21H
N75-28112
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# DETERMINATION OF FAILURE LIMITS FOR STERILIZABLE SOLID ROCKET MOTOR

## FINAL REPORT

December 1974



aerojet solid propulsion company

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# DETERMINATION OF FAILURE LIMITS FOR STERILIZABLE SOLID ROCKET MOTOR

## FINAL REPORT


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DECEMBER 1974

**Prepared Under:**

JPL Contract 953848


This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.


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## I. SUMMARY AND CONCLUSION

Following a structural evaluation to establish probable failure limits, a series of environmental tests involving temperature cycling, sustained acceleration and vibration were conducted on an 18-inch diameter solid rocket motor. This motor had previously been subjected to over 320 hours of heat sterilization at 275°F and employed a flexible grain retention system to accommodate this wide range of temperature.

Despite the fact that thermal, acceleration and vibration loads representing a severe overtest of conventional environmental requirements were imposed on the sterilizable motor, no structural failure of the grain or flexible support system was detected. In view of this, the following significant conclusions are considered justified;

1. The flexible grain retention system, which permitted heat sterilization at 275°F on the test motor, can readily be adopted to meet the environmental requirements of an operational motor design.

2. If further substantiation of structural integrity is desired, the motor used in this test program is considered acceptable for static firing.

## II. INTRODUCTION

This report describes the analysis and testing performed by the Aerojet Solid Propulsion Company (ASPC) in order to determine realistic failure limits for a heat sterilizable solid rocket motor. The program was sponsored by the Jet Propulsion Laboratory under JPL Contract 953848 as an extension of the work ASPC had performed under NASA Contract NASI-10861.

During the original program ASPC designed and built two 18-inch diameter flight weight spherical motors which successfully withstood over 320 hours of sterilization at a temperature of 275°F. One of these motors was static fired and the second motor was selected for the environmental testing program described herein.

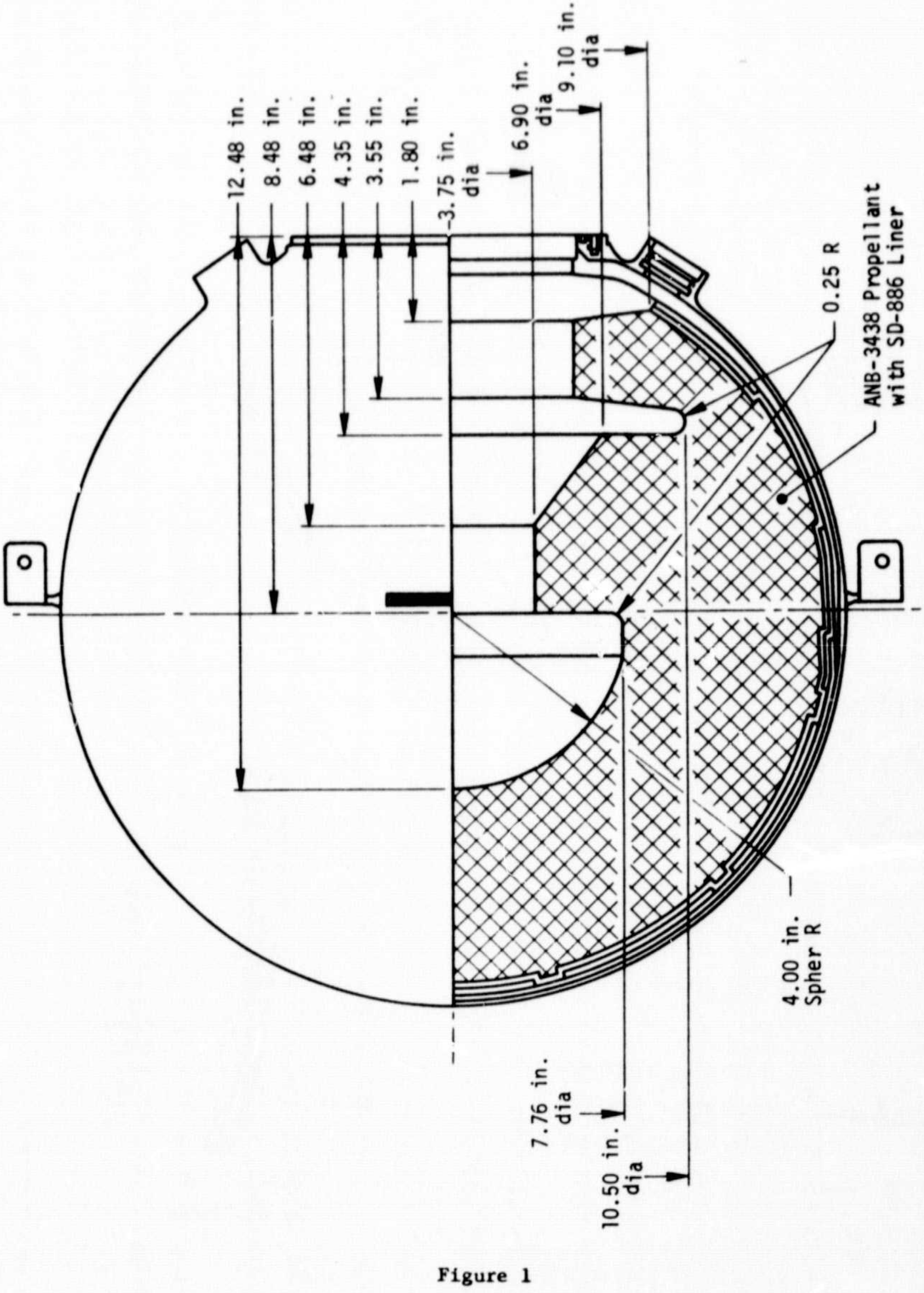
One of the key features of these motors is a flexible grain retention system which minimizes the loads imposed on the propellant grain during the large temperature excursions associated with heat sterilization. The system had performed satisfactorily during sterilization cycles, but its flexible nature was the subject of concern with respect to environmental loads which might be expected during flight applications. The primary objective of the additional investigation was to obtain design information which would be of value in adopting this system to operational use. The actual program consisted of a structural analysis to determine approximate failure loads for various test conditions followed by a series of thermal, acceleration and vibration tests.

## III. TEST MOTOR CONFIGURATION

The sterilizable motor tested in this program had an 18-inch diameter spherical configuration as indicated in Figure 1. The thin wall titanium chamber had been developed for another space motor application and the insulation system was modified to incorporate a flexible grain retention system. This consisted of splitting the thickness of the insulation and attaching the two parts through a number of circular discs of rubber impregnated glass cloth. By bonding the discs to the insulation in alternate locations as indicated in Figure 2, a support system was obtained which was very soft in the radial direction, but which had acceptable stiffness to react shear loading.

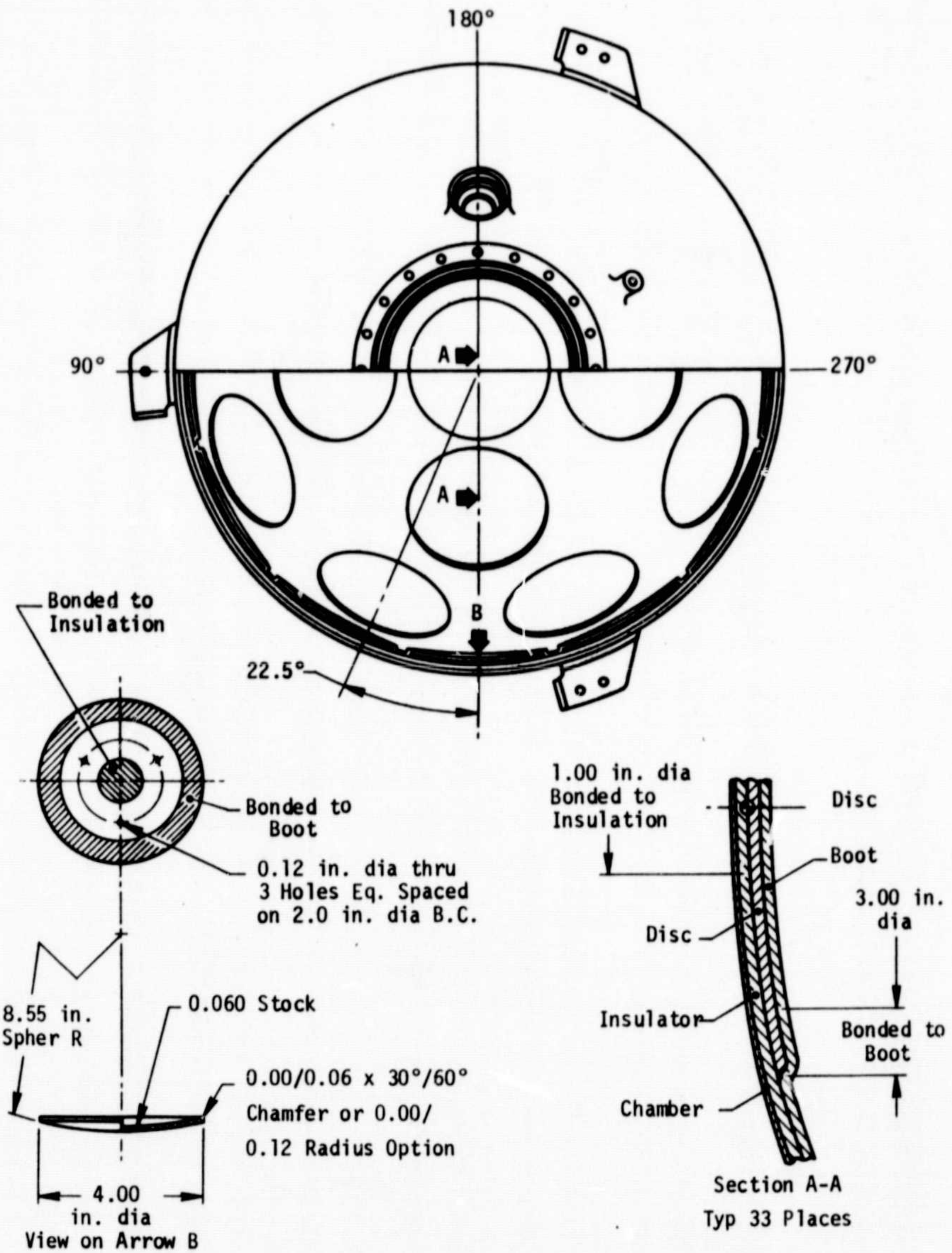
## IV. STRUCTURAL EVALUATION

Prior to performing environmental tests on the motor, a structural evaluation of the design was undertaken in order to determine approximate




Test Motor Configuration

Figure 1




Details of Flexible Grain Retention System

Figure 2

load values at which failures might be anticipated. This evaluation consisted of a limited material characterization test program on the various bond systems combined with structural analysis of the actual motor configuration. In accordance with a program ground rule, the predicted failure limits were based on 50 percent probability. This is in marked contrast to conventional structural evaluations where margins of safety are computed on the basis of 95 to 99 percent probability. Superimposed upon these predicted failure points were the requirements of the proposed Mars Sample Return Mission(1). Therefore, the goals of this study were as follows:

1. Determine the points at which the motor would have a 50/50 chance of survival under conditions of low temperature, acceleration, and vibration.

2. Compare these points with those required by the proposed Mars Sample Return Mission.

3. Based on the data from 1 and 2, determine test levels which would demonstrate the motors capability in these three areas. The intent is to demonstrate that the sterilized rocket motor system would successfully withstand the levels of testing required for the Mars Sample Return Mission.

A complete description of the testing and analysis conducted during the structural evaluation phase of the program is contained in Technical Progress Report No. 1197-PR-1, dated June 1974. For convenience, however, the important results and conclusions with respect to the various environmental loadings are summarized below.

## A. THERMAL LOADS

Based on analysis the critical area in the motor for thermal loading is the bond between the reinforced discs and the insulation. Uncertainty associated with the stress-free temperature of the propellant

(1): "A feasibility Study of Unmanned Rendezvous and Docking in Mars Orbit", Martin Marietta Corp, W. T. Scofield, program manager, Prepared for JPL under contract #953746, June, 1974.

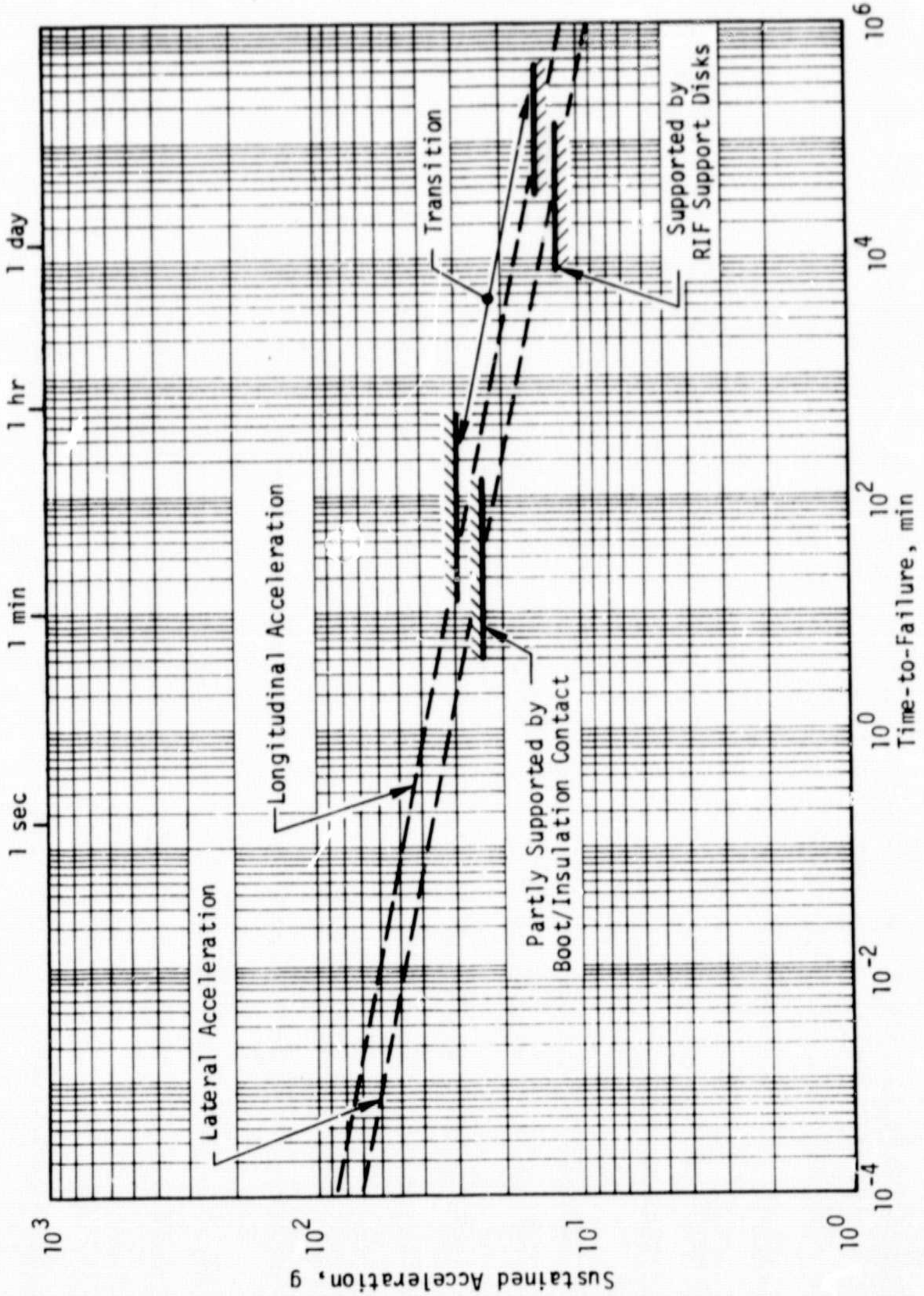
after sterilization makes it difficult to accurately predict a low temperature limit at which bond failure would be expected. Based on an assumed complete shifting of the stress-free temperature to the maximum sterilization temperature of 275°F, however, a minimum temperature of +5°F was selected for the first thermal cycling tests. It was anticipated that, should failure not occur during this and the subsequent acceleration and vibration tests, additional thermal testing to a lower temperature might be conducted. The requirements for the Mars Sample Return is -10°F.

## B. SUSTAINED ACCELERATION

Acceleration loads provide the prime reason for having the grain retention discs in the design. The loads are principally reacted tangentially by those discs which are aligned in the plane perpendicular to the acceleration vector. By using a large number of discs, uniformly spaced over the spherical case, the system is nearly omni-directional and the grain response is similar in most directions.

For sustained acceleration, as opposed to vibration or shock acceleration, the bond shear stresses have been calculated as if the grain were free to move without any restraint other than the retention discs. It had been previously calculated that a longitudinal acceleration of 19 g could be sustained for one minute before the grain would contact the case, offsetting the thermal shrinkage gap. Support from the case would reduce the load proportion supported by the retention discs, in effect adding the spring rate of the grain itself to the spring rate of the discs. However, in predicting the bond shear failure envelope, support from the case was ignored. Figure 3 shows the sustained acceleration as function of time-to-failure for the 50/50 failure probability. Typical acceleration capabilities are as follows:

| | |
|---|---|
| 1 second | 55 g |
| 1 minute | 38 g |
| 1 day | 20 g |




Sustained Acceleration vs Time-to-Failure
of the Rubber/Rubber Bond Line at 77°F (25°C)

Figure 3

It is apparent that a test condition meeting the 50/50 failure target cannot be reasonably attained. In view of this a nominal test condition of 20 g's for one minute was selected. This value is considered to be well above that required by the Mars Sample Return requirement which is 30g for 22ms.

### C. VIBRATION

Vibration is a special case of acceleration, wherein the response interacts to amplify the input acceleration. Therefore, the same failure limits as were determined for sustained acceleration can be employed for test environment criteria. However, calculation of test input conditions required to achieve the target 50/50 failure probability would involve an extensive analysis along with special material characterization testing. The more direct approach is to measure the response levels in a sine survey at a low acceleration. This can be used to determine the amplification factor as a function of frequency, allowing the prediction of response as a function of input. In this way, time-to-failure can be calculated from the resonant frequencies and the test input accelerations can be calculated from the 50/50 failure probability acceleration at that time-to-failure point. On the basis of the above rational, it was decided to establish vibration input limits after evaluating the low level sine survey test results.

## V. TEST RESULTS

Environmental testing of the motor was conducted during the period from 28 May to 15 September 1974. Individual reports covering the thermal and vibration tests have been submitted previously[(2),(3)], but portions of these reports have been reproduced here for completeness.

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(2) "Results of Thermal Testing", ASPC Technical Progress Report 1197-PR-2, June 1974

(3) "Vibration Test Report for the Sterilizable Solid Rocket Motor No. 1", ASPC Report dated 23 August 1974

## A. INITIAL THERMAL TESTING

Starting on 28 May 1974 the motor was subjected to two cycles between 77°F (25°C) and 5°F (-15°C), one of which was conducted in 18°F (10°C) increments. Grain bore measurements were taken at each step. At the final 5°F (-15°C) step, the motor was X-ray inspected and found to be free from structural damage.

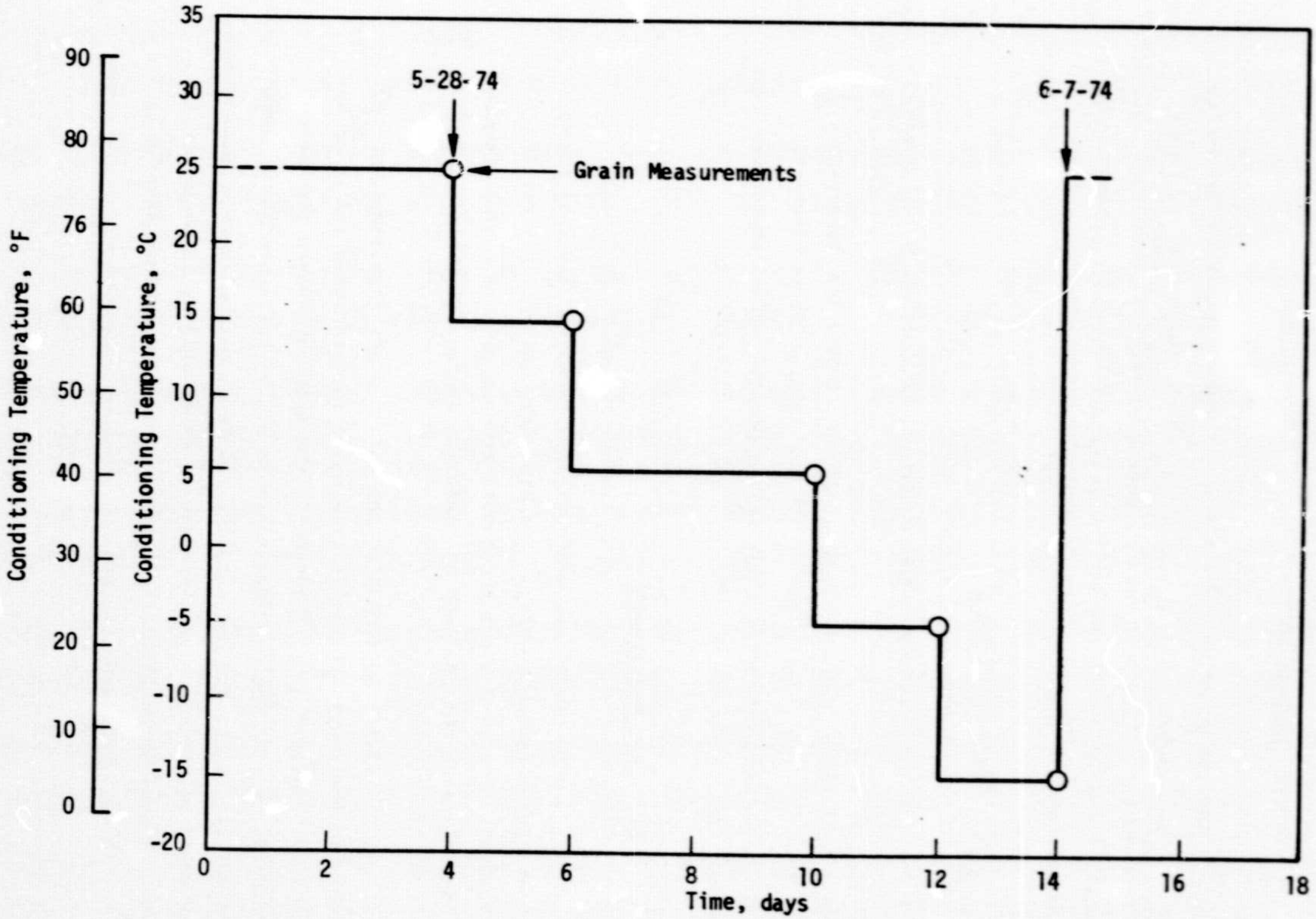
### 1. Test Conditions

The first cycle was conducted as planned, with two days allowed for reaching thermal equilibrium, except where weekends imposed additional soak time. Figure 4 shows the conditioning box temperature as a function of time. The second cycle was delayed by an electrical malfunction, but was otherwise completed as planned. The temperature-time profile is given in Figure 5.

### 2. Test Measurements

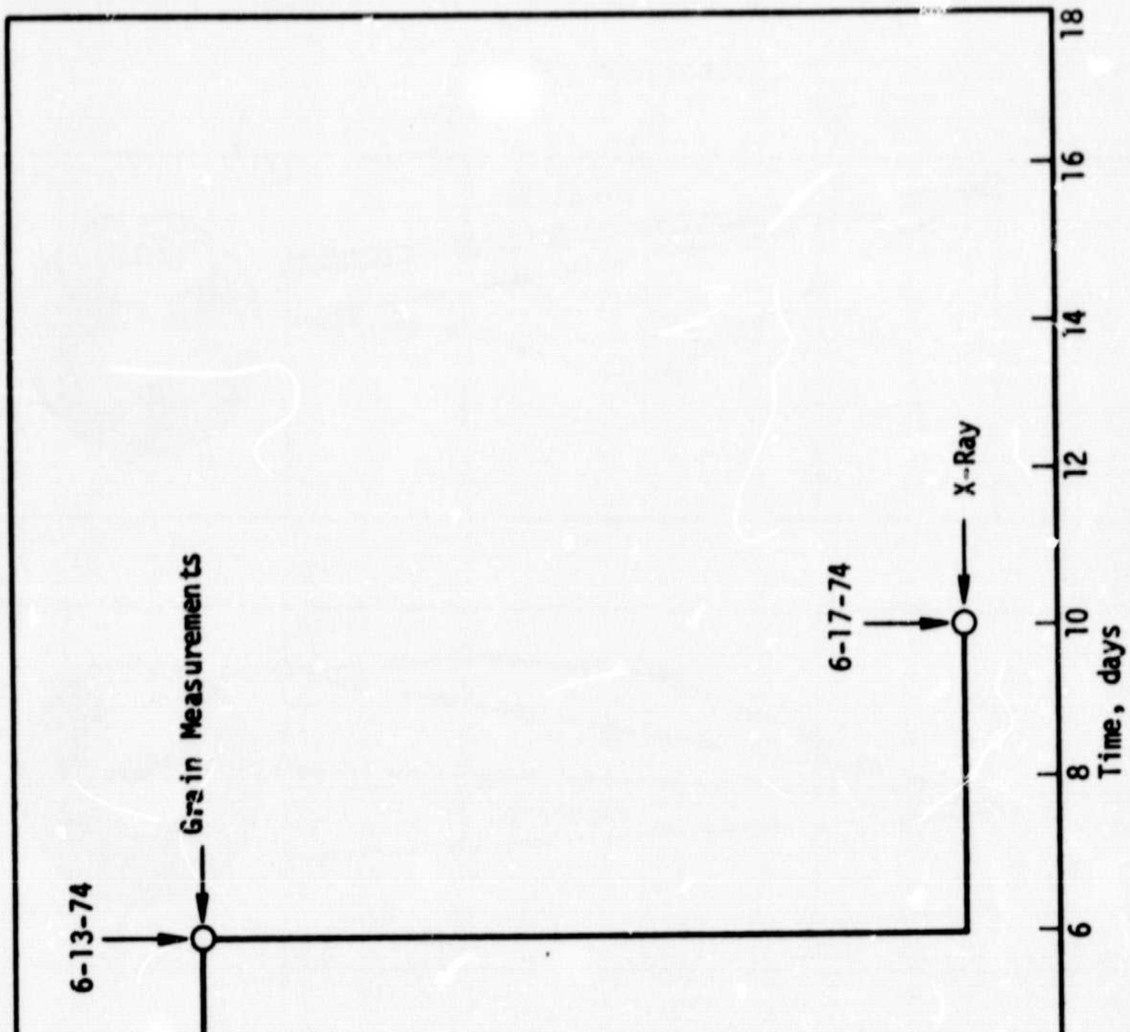
The propellant grain was monitored for internal shape changes at each temperature step. Two diameters and the internal length were measured. Figure 6 shows these measurements plotted against temperature, and indicates the sequence of temperatures and measurement locations.

It is apparent that the data are not consistent, in that the predicted free shrinkage is in some cases substantiated and in other instances contradicted or not repeated. The apparent reason for these discrepancies is that the machined surfaces of the grain are not uniform and the actual changes are quite small. Somewhat more elaborate inspection tooling would be needed to assure adequate repeatability in measurement location. Visual inspection of the propellant grain surface at 77°F (25°C) and 5°F (-15°C) revealed no changes.



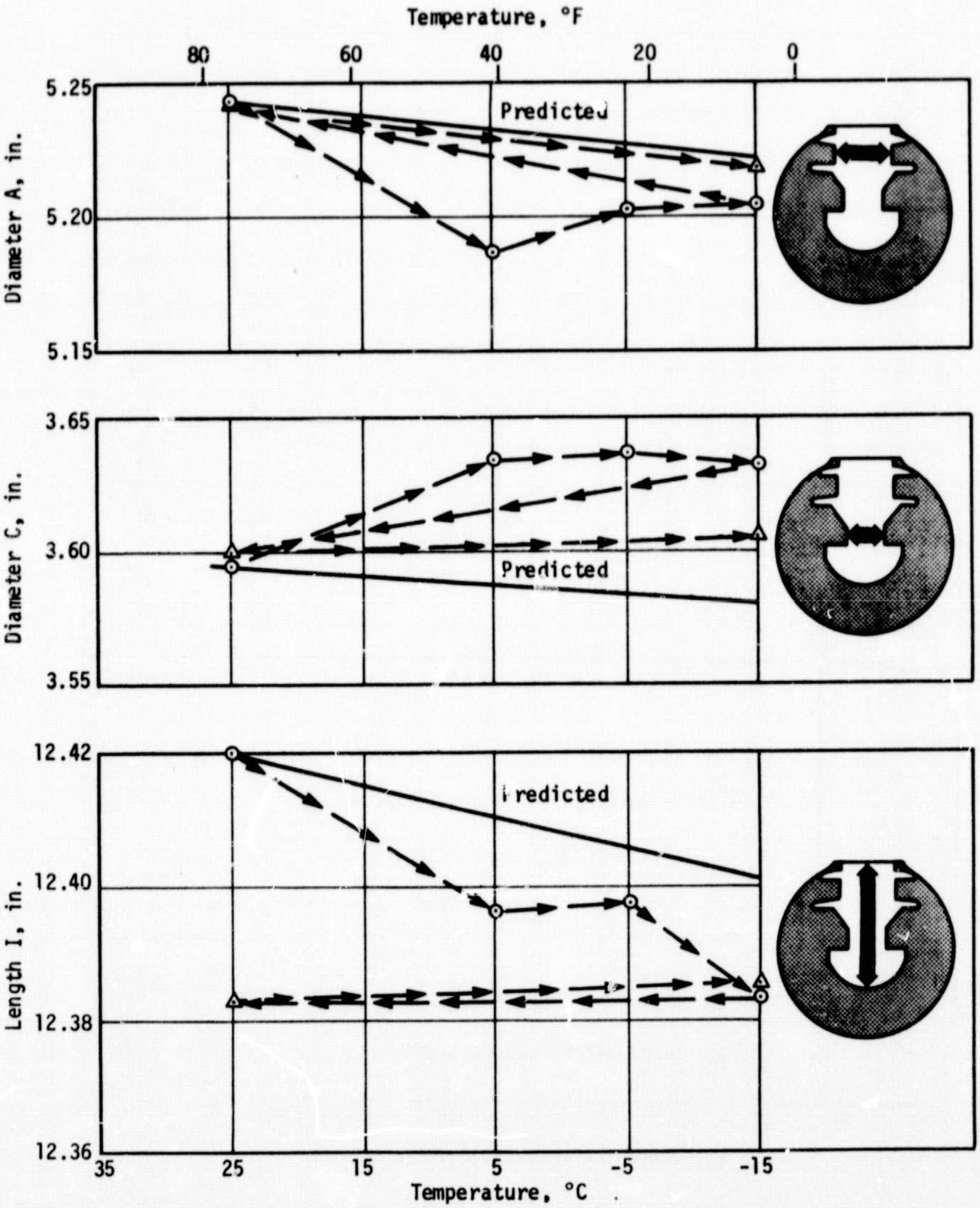

Conditioning Temperature vs Time - Cycle 1

Figure 4




Conditioning Temperature vs Time - Cycle 2

Figure 5




Effect of Temperature on Grain Internal Dimensions

Figure 6

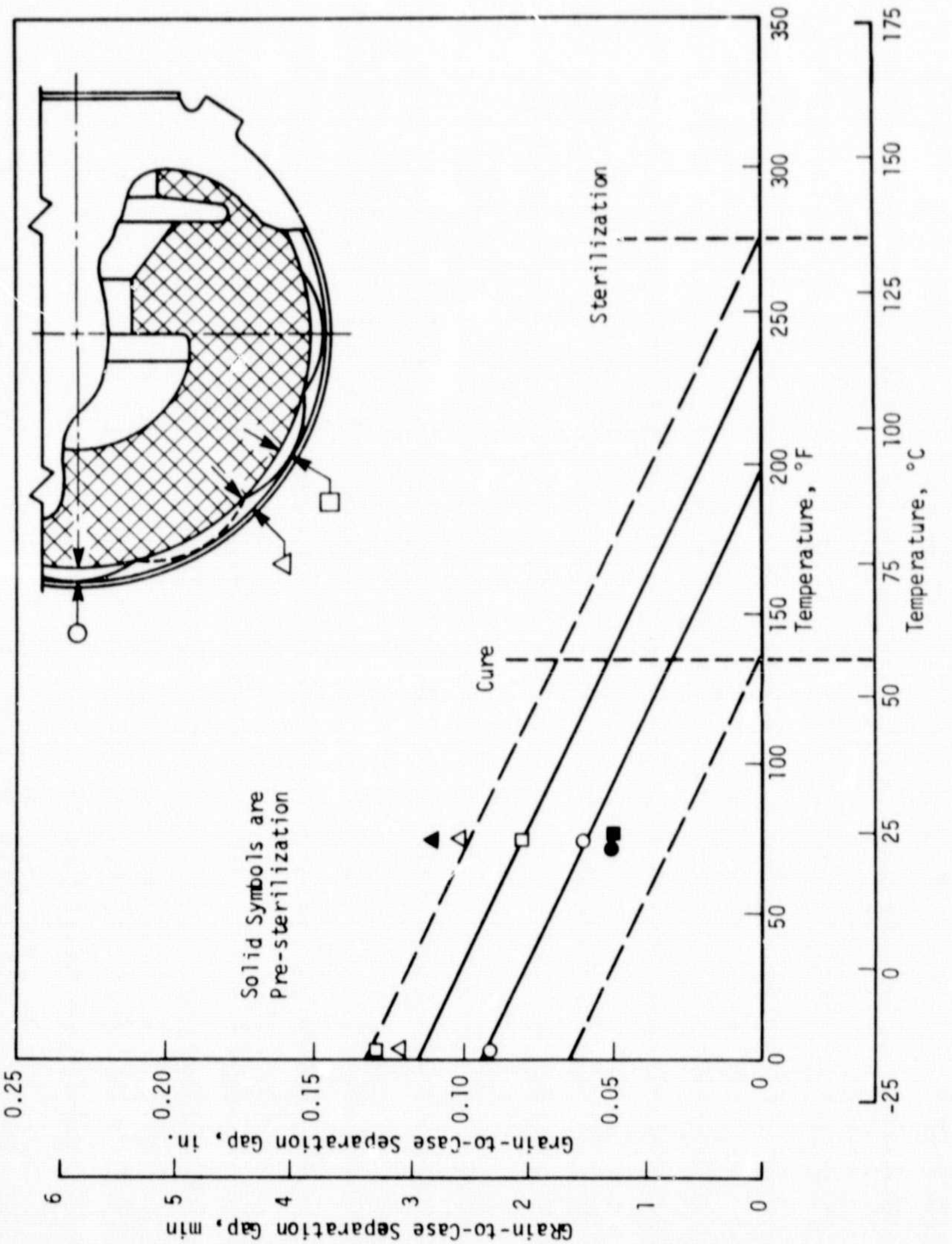
### 3. Radiographic Inspection

At the last temperature step ($5^{o}F$), the motor was packaged with thermal insulation and delivered to the radiographic facility for X-ray inspection. Radiographs were taken at 30-degree increments for each end, concentrating on tangential views of the bondlines. These were supplemented by centerline and axial views. There were no indications of bond failure at any location.

Direct measurement of the shrinkage gap was obtained from the X-ray films. The data shown in Figure 7 are representative and tend to verify the free-shrinkage response of the grain to reduced temperature. Extrapolation of the data to the zero-gap intercept might indicate apparent "stress-free" temperatures, except that the pre-sterilization gaps at ambient temperature would also indicate stress-free temperatures in excess of the cure temperature of $135^{o}F$ ($57^{o}C$). Thus, it is obvious that the imperfect fit of the rubber insulation and retention system components created significant gaps at the cure temperature, which allowed considerable unrestrained grain expansion during sterilization heatup. This reduced the amount of compression on the grain at the sterilization temperature of $275^{o}F$ ($135^{o}C$), thereby reducing the inner bore deformations below predicted levels, as indicated previously. The as-cast gap also correlates with the propellant weight being less than that calculated.

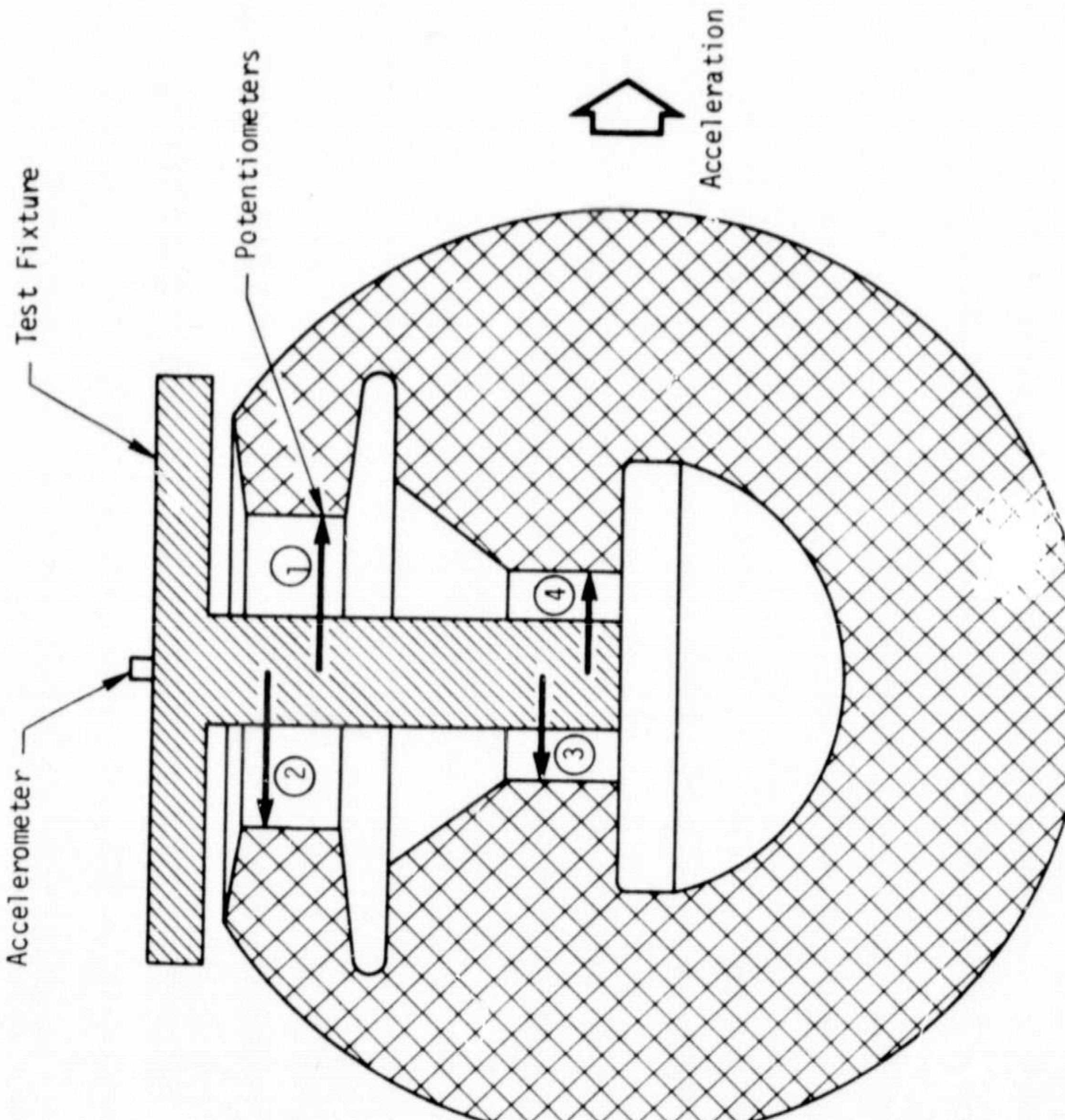
## B. ACCELERATION TESTING

Acceleration testing of the sterilizable motor was subcontracted to Wyle Laboratories in Norco, California, and a copy of the test report covering that test is contained in Appendix A. In summary the motor was mounted on a centrifuge and subjected to approximately 19 g's of lateral acceleration for a period of one and one-half minutes. The test was conducted on 11 July 1974 at an ambient temperature ranging from 50 to $90^{o}F$ and the reported accelerations were measured at the c.g. of the motor. Deflection gages located as indicated in Figure 8 were continuously recorded during the test and plots of deflection and acceleration measurements vs time are contained in Figure 9.



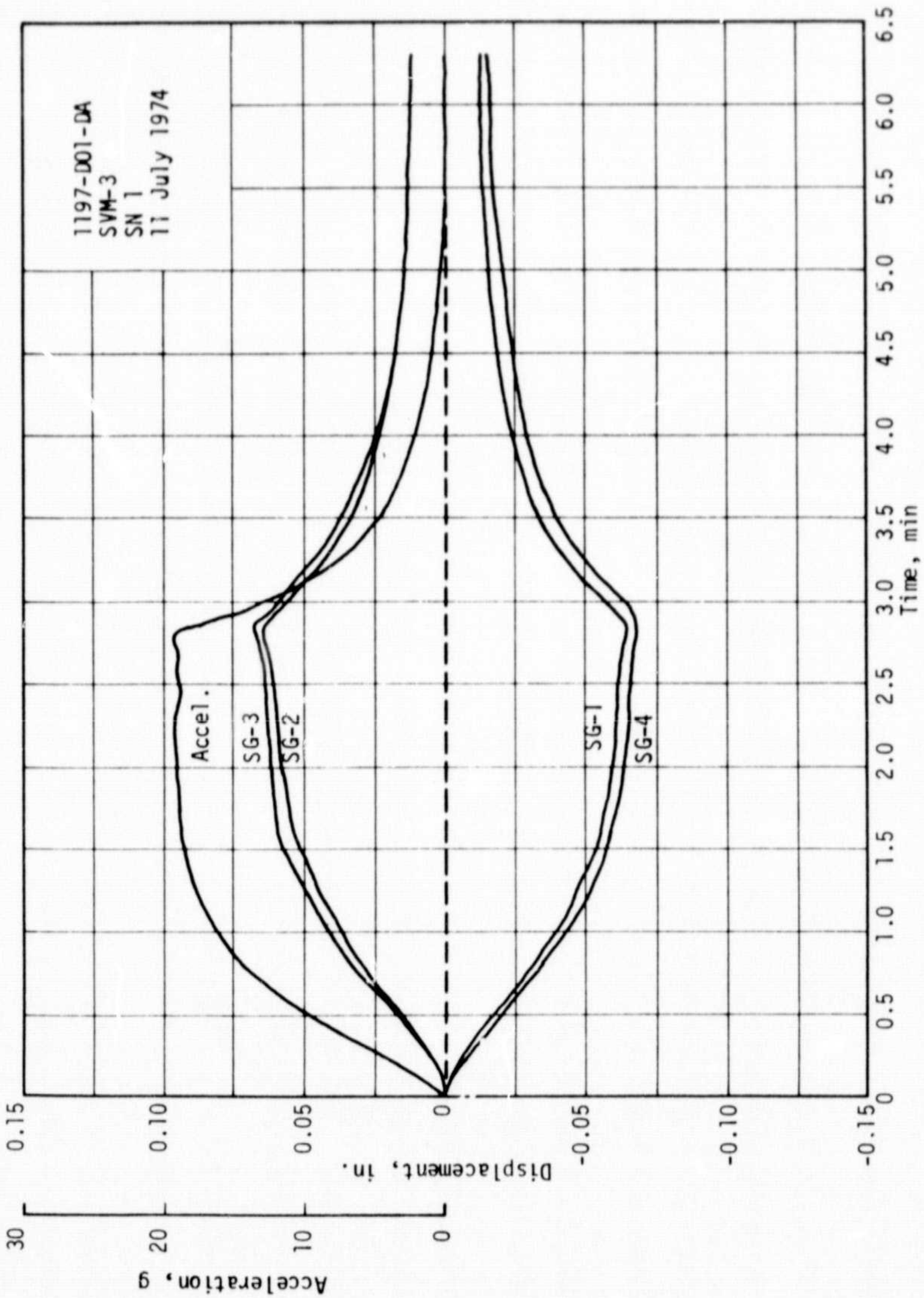

Effect of Temperature on Grain Separation Gap

Figure 7




Location of Deflection Gages in Acceleration Test

Figure 8




Acceleration and Displacements vs Time during Centrifuge Test

Figure 9

No visible damage to the motor was noted following the acceleration test and subsequent radiographic inspection at ASPC indicated no changes from the pre-test inspection results.

## C. VIBRATION TESTING

During the period of 29 July through 9 August 1974, Sterilizable Motor No. 1 was subjected to a series of sinusoidal sweep and random vibration tests in accordance with the test procedures and requirements specified in ASPC test plan, "Vibration Test Plan for the Sterilizable Solid Rocket Motor," dated 13 May 1974 (reference Appendix B).

The test motor was installed in a rigid magnesium vibration test support fixture through a bolted attachment of the three motor mounting lugs to the test fixture, and was maintained in a vertical "nozzle up" attitude during all phases of the vibration test program.

The sinusoidal and random vibration tests were conducted along the thrust (X) and the transverse (Y) axis of the sterilizable motor at ambient temperatures ($75^{o}$ to $85^{o}F$) in the ASPC Test Operations vibration test facility.

The specific objectives of the Sterilizable Motor Vibration Test Program were:

1. To determine the dynamic response characteristics of the propellant retention system over a frequency range of 10 to 2000 Hz for both thrust and transverse axis low-level ($\pm 1$ to $\pm 3G$) sinusoidal sweep input excitation functions.

2. To evaluate the frequency response functions obtained from the low-level sine sweep survey tests with respect to the results of the pre-test motor stress analysis and determine the vibration test conditions that would induce failure of the propellant retention system.

3. To determine the thrust and transverse axis sinusoidal and random vibration test input spectra that would give the motor a 50/50 chance of survival when subjected to the selected test input spectra.

4. To conduct sinusoidal and random vibration endurance tests along each of the two orthogonal motor test axes using vibration input spectra that would represent a reasonable overtest condition of the motor or meet the Mars Sample Return requirements.

5. To conduct a comprehensive post-test radiographic inspection of the motor and determine if the propellant retention system experienced any structural damage during the vibration test program.

Six crystal accelerometers were mounted on the vibration test support and on, and within, the motor during each phase of the two-axis vibration tests. One accelerometer was mounted on the test fixture immediately adjacent to the $90^{\circ}$ motor mounting lug and was used as the input control accelerometer during all phases of the two-axis motor vibration tests. One accelerometer was mounted on the apex of the forward dome and another was mounted on the aft dome adjacent to the nozzle boss. Three accelerometers were mounted at various axial distances along the propellant bore. See Figures 1 and 2 of Appendix B for accelerometer locations.

The responses of the six accelerometers were continuously recorded on a nagnetic tape recorder during each sinusoidal sweep and random vibration test.

The acceleration response data recorded at the six accelerometers during the sinusoidal survey and sinusoidal vibration qualification tests were played back through a tracking filter (5 Hz band width) onto an X-Y plotter after completion of each sine sweep test. The input and response data recorded during the sinusoidal sweep tests are presented in the form of filtered acceleration versus frequency X-Y plots.

The acceleration response data of the six accelerometers were continuously recorded on a magnetic tape recorder during each 4-min random vibration test.

Each channel of taped recorded random response data was played back onto a loop recorder and 15-sec data loop was recorded. A power spectral density analysis was performed on each 15-sec data sample using analyzer band

widths of 5 Hz from 20-120 Hz, and 50 Hz from 120-2000 Hz. The input and response data recorded at each accelerometer during the random vibration qualification tests are presented in this report in the form of Power Spectral Density versus Frequency plots.

Visual inspections of the motor and test support fixtures were conducted immediately after completion of each major test phase conducted in each of the two motor test axes. Bolted attachments of the exciter-to-fixture and test motor-to-fixture were inspected visually and bolt torque checks were made after each test to ensure that the measured vibratory responses represented the dynamic response behavior of the motor and were not influenced by changes in the structural attachment of the motor to the fixture, or the fixture to the electrodynamic exciter.

A summary of the specific tests and the test sequence is indicated in Table 1.

Table 1

SUMMARY OF VIBRATION TESTS

| Test Axis | Test Type | Test Date |
|---|---|---|
| Transverse Y | ± 1-G Sine Sweep Survey Test, 10-2000 Hz, 1 oct/min | 29 July 1974 |
| Thrust (X) | ± 1-G Sine Sweep Survey Test, 10-2000 Hz, 1 oct/min | 30 July 1974 |
| Thrust (X) | ± 3-G Sine Sweep Survey Test, 20-2000 Hz, 1 oct/min | 30 July 1974 |
| Thrust (X) | Sine Sweep Vibration Qualification Test, ± 7.5 G from 10-50 Hz, and ± 5.0 G from 50-200 Hz, 1 oct/min | 5 August 1974 |
| Thrust (X) | 4-Min/Axis Random Vibration Qualification Test, 20-2000 Hz, 8.55 G-RMS Overall | 7 August 1974 |
| Transverse Y | 4-Min/Axis Random Vibration Qualification Test, 20-2000 Hz, 8.55 G-RMS Overall | 8 August 1974 |
| Transverse Y | Sine Sweep Vibration Qualification Test, ± 7.5 G from 10-200 Hz, 1 oct/min | 8 August 1974 |
| Transverse Y | Post-test ± 1-G Sine Sweep Survey Test, 25-150 hz, 1 oct/min | 9 August 1974 |
| Complete Motor | Radiographic Inspection | 12 August 1974 |

## 1. Principal Results of Thrust (X) Axis Tests

The principal results obtained during the thrust (X) axis ± 1-G, and ± 3-G sine sweep survey tests, and during the thrust (X) axis Sinusoidal Sweep Vibration Qualification Test are presented in the form of a tabular summary in Table 2.

Analysis of the frequency response data listed in Table 2 shows that the propellant mass responded principally as a rigid body with respect to the compliance of the 33-disc rubber propellant retention system when the motor was subjected to thrust axis sine sweep vibratory excitation. The fundamental thrust axis resonant frequency of the propellant mass with respect to the propellant retention system was about 100 Hz, with a corresponding dynamic amplification factor of about 10, when the motor was subjected to the ± 1-G sine sweep vibratory input level.

A thrust (X) axis ± 3-G sine sweep survey test was conducted after the ± 1-G sine survey test had been completed and the X-Y plots of the ± 1-G sine survey response data had been analyzed. The objective of this supplemental ± 3-G sine sweep survey test was to obtain an estimate of the non-linearily in amplitude response that was expected to occur within the 33-disc rubber propellant retention system. Analysis of the frequency and acceleration amplitude response levels listed in Table 2 for propellant-mounted accelerometers A-4-X, A-5-X, and A-6-X show that at the ± 3-G input level the resonant frequencies of the propellant mass decreased from about 100 Hz at the ± 1-G input level to about 92.5 Hz at the ± 3-G input level. Similarly, the acceleration response level of about ± 10 G (at 100 Hz) at the ± 1-G input level increased to ± 20 G (at 92.5 Hz) at the ± 3-G input level. If the propellant retention system was linear, a response amplitude of about ± 30-G would be expected at the propellant-mounted accelerometers at the ± 3-G input level.

A comprehensive evaluation of the results of the pre-test stress analysis of the motor and propellant retention system was conducted with respect to the results of the ± 1-G and ± 3-G thrust axis sine survey

Table 2

COMPARISON SUMMARY OF MAJOR RESONANT FREQUENCIES AND CORRESPONDING ACCELERATION RESPONSE LEVELS RECORDED DURING THE THRUST (X) AXIS ± 1-G & ± 3-G SINE SWEEP SURVEY TESTS AND THE THRUST AXIS SINUSOIDAL QUALIFICATION TEST OF THE STERILIZABLE MOTOR NO. 1

| Accelerometer Designation | Accelerometer Location | ± 1-G Survey Test | | ± 3-G Survey Test | | Sine Qual. Test | |
|---|---|---|---|---|---|---|---|
| | | Freq (Hz) | Level (±G) | Freq (Hz) | Level (±G) | Freq (Hz) | Level (±G) |
| A-1-X (Input Control) | On test fixture adjacent to 90° motor mounting lug. | 10-2000 | 1.0 | 20-2000 | 3.0 | 10-50<br>50-200 | 7.5<br>5.0 |
| A-2-X | On apex of exterior surface of forward dome. | 100<br>740<br>1100 | 4.5<br>4.0<br>8.9 | 92<br>730<br>1090 | 8.3<br>12.7<br>26.5 | 84 | 10.9 |
| A-3-X | On aft dome at 90° and adjacent to nozzle boss. | 100<br>740<br>1520 | 5.1<br>3.8<br>4.3 | 92<br>730<br>1530 | 8.2<br>10.5<br>11.6 | 84 | 10.8 |
| A-4-X | On centerline of the forward section of the propellant bore. | 100<br>725 | 9.8<br>0.55 | 92.5<br>710 | 20.0<br>2.0 | 85 | 27.2 |
| A-5-X | On center section of the propellant bore. | 100<br>725 | 9.8<br>0.96 | 92.5<br>705 | 20.0<br>3.0 | 85 | 27.0 |
| A-6-X | On aft section of the propellant bore. | 102<br>395<br>740 | 10.1<br>0.58<br>0.68 | 93<br>390<br>700 | 20.0<br>1.92<br>2.18 | 85 | 29.0 |

tests. The results of this comparative evaluation showed that the propellant retention system was capable of withstanding a vibratory level of 30 G, however, the results of the stress analysis showed that the motor lug/bolt attachment could only withstand a maximum motor response level of 25 G. Structural failure of the motor lug/bolt attachment war expected to occur at a lower input level (± 5 G) than failure of the propellant retention system.

The guidelines used in the selection of thrust axis and random vibration input spectra were obtained fron the enclosure to the letter from Mr. John Mellin, Martin Marietta Aerospace, to Mr. Don Udlock, JPL, dated 22 March 1974. The sinusoidal and random vibration input spectra cited in the subject letter were based on estimated environmental levels for MAV (Mars Ascent Vehicle) in the URDMO (Mars Sample Return) mission. These test levels are as follows:

Thrust Axis
Sinusoidal Vibration
Test Input Spectrum

| Freq. Range | Input Level |
|---|---|
| (Hz) | (± G) |
| 10-50 | 7.5 |
| 50-200 | 5.0 |

(Limited to 0.5" double amplitude displacement)

Thrust Axis
Random Vibration Test
Input Spectrum

| Freq. Range | Input Level |
|---|---|
| (Hz) | ($G^2$/Hz) |
| 20-200 | Increase at 3db/octave |
| 200-1000 | 0.054 |
| 1000-2000 | Decrease at 6db/octave |

(8.7 G-rms overall)

The thrust (X) axis sinusoidal vibration qualification consisted of one sweep up from 10 to 200 in accordance with the above input spectrum using a logarithmic sweep rate of one octave/min. The thrust axis

Sinusoidal Vibration Qualification Test was followed by 4-min random vibration test that was conducted in accordance with the random vibration input spectrum described above. The principal results obtained during the thrust (X) axis Sinusoidal Vibration Qualification Test are listed in Table 2 on a comparison basis with corresponding results obtained during the thrust (X) axis ± 1-G and ± 3-G sine sweep survey tests. The principal results obtained during the thrust (X) axis Random Vibration Qualification Test are shown in Table 5.

The sinusoidal vibration qualification test input spectrum that was applied along the thrust axis of the motor differed from the recommended sinusoidal vibration input spectrum (Martin Marietta Aerospace) in the frequency range of 50 to 200 Hz. The recommended sinusoidal vibration qualification test input spectrum specified an acceleration input level of ± 7.5 G from 10-200 Hz. The sinusoidal vibration test input level that was applied to the thrust axis of the motor in the frequency range of 50 to 200 Hz was ± 5-G.

The 4-min/axis random vibration qualification test of the motor was conducted in accordance with the random vibration input spectrum that was described in the Martin Marietta Aerospace letter, dated 22 March 1974.

The principal results obtained during the 4-min thrust axis random vibration qualification test are listed in tabular form in Table 5.

2. Principal Results of Transverse (Y) Axis Tests

The principal results obtained during the transverse Y-axis ± 1-G sine sweep survey test and the Y-axis Sinusoidal Sweep Vibration Qualification Test are presented in tabular summary form in Table 3.

Analysis of the frequency response data listed in Table 3 shows that the propellant mass responded principally as a rigid body with respect to the compliance of the 33-disc rubber propellant retention system when the motor was subjected to transverse Y-axis sine sweep vibration excitation.

Table 3

COMPARISON SUMMARY OF MAJOR RESONANT FREQUENCIES AND CORRESPONDING ACCELERATION RESPONSE LEVELS RECORDED DURING THE TRANSVERSE Y AXIS $\pm$ 1-G SINE SWEEP SURVEY TEST AND THE Y-AXIS SINUSOIDAL SWEEP VIBRATION QUALIFICATION TEST OF STERILIZABLE MOTOR NO. 1

| Accelerometer Designation | Accelerometer Location | $\pm$ 1-G Sine Survey Test | | Sine Sweep Qual. Test | |
|---|---|---|---|---|---|
| | | Freq. (Hz) | Level ($\pm$ G) | Freq. (Hz) | Level ($\pm$ G) |
| A-1-Y (Input Control) | On test fixture adjacent to 90$^{\circ}$ motor mounting lug | 10-2000 | 1.0* | 10-200 | 7.5* |
| A-2-Y | On apex of exterior surface of motor forward dome | 98<br>150<br>560<br>740<br>1000<br>1180 | 2.1<br>1.12<br>19.5<br>5.1<br>10.0<br>13.2 | 41<br>56<br>73 | 8.5<br>7.5<br>7.2 |
| A-3-Y | On motor aft dome at 90$^{\circ}$ and adjacent to the nozzle boss | 96<br>680<br>860<br>1700 | 1.73<br>11.5<br>11.9<br>12.1 | 30<br>57 | 8.0<br>9.5 |
| A-4-Y | On forward center line section of the propellant bore | 100<br>975 | 6.25<br>1.48 | 57<br>83 | 23.8<br>14.1 |
| A-5-Y | On center section of the propellant bore | 100<br>960 | 7.0<br>2.0 | 58<br>85 | 26.2<br>5.8 |
| A-6-Y | On aft section of the propellant bore | 102<br>800 | 7.0<br>0.8 | 56<br>78 | 27.5<br>6.4 |

* Limited to 0.5 inches double amplitude displacement.

The fundamental resonant frequency of the propellant mass with respect to the propellant retention system was 100 Hz, with a corresponding dynamic amplification factor of 6.25-7.00, when the motor was subjected to the transverse Y axis ± 1-G sine sweep vibratory input level.

It should be noted that the fundamental resonant frequencies recorded during the Y-axis ± 1-G sine survey test were similar to those recorded during the thrust axis ± 1-G sine survey test, namely 100 Hz, at the propellant-mounted accelerometers.

The dynamic amplification factors (9.8-10.1) recorded at 100 Hz at the three propellant-mounted accelerometers during the thrust (X) axis ± 1-G sine survey test were appreciably higher than the corresponding dynamic amplification factors (6.27-7.00) recorded at 100 Hz during the transverse Y-axis ± 1-G sine survey test. Table 4 was included in this report as a convenience to the reader so that a comparison of responses of the propellant-mounted accelerometers with respect to both thrust (X) axis and transverse (Y) axis ± 1-G sine sweep excitation could be made.

A similar evaluation of the results of the pre-test stress analysis of the motor and propellant retention system was conducted with respect to the results obtained from the transverse Y-axis ± 1-G sine sweep survey test. The results of this comparative evaluation showed that the motor lug/bolt attachment, the propellant and propellant retention system were capable of withstanding the ± 7.5 G (from 10-200 Hz) sinusoidal vibration qualification environment cited in the Martin Marietta Aerospace letter, dated 22 March 1974. The results of the pre-test stress analysis showed that the motor lug/bolt attachment, the propellant, and the propellant retention system could withstand a motor vibratory acceleration level of ± 30 G. It was estimated, based on the observed non-linear behavior of the propellant retention system, that the 3 propellant-mounted accelerometers would not (on a 50/50 chance basis) exceed ± 30 G if the recommended ± 7.5 G (from 10-200 Hz) were applied to the transverse Y axis of the motor. The results of the pre-test stress analysis showed that the motor and the propellant

Table 4

SUMMARY OF MAJOR RESONANT FREQUENCIES AND CORRESPONDING DYNAMIC AMPLIFICATION FACTORS RECORDED DURING THE ± 1-G SINE SWEEP SURVEY TESTS IN THE THRUST (X) AND TRANSVERSE (Y) AXES OF THE STERILIZABLE MOTOR NO. 1

| Accelerometer Location | Thrust (X) Axis Test | | | Transverse (Y) Axis Test | | |
|---|---|---|---|---|---|---|
| | Accelerometer Designation | Freq. (Hz) | Level (+G) | Accelerometer Designation | Freq. (Hz) | Level (+G) |
| On test fixture adjacent to the 90° motor mounting lug | A-1-X* | 10-2000 | 1.0 | A-1-Y* | 10-2000 | 1.0 |
| On apex of exterior surface of motor forward dome | A-2-X | 100<br>740<br>1100 | 4.5<br>4.0<br>8.9 | A-2-Y | 98<br>150<br>560<br>740<br>1000<br>1180 | 2.1<br>1.12<br>19.5<br>5.1<br>10.9<br>13.2 |
| On motor aft dome at 90° and adjacent to the nozzle boss | A-3-X | 100<br>740<br>1520 | 5.1<br>3.8<br>4.3 | A-3-Y | 96<br>680<br>860<br>1700 | 1.73<br>11.5<br>11.9<br>12.1 |
| On forward centerline section of the propellant bore | A-4-X | 100<br>725 | 9.8<br>0.65 | A-4-Y | 100<br>975 | 6.25<br>1.48 |
| On center section of the propellant bore | A-5-X | 100<br>725 | 9.8<br>0.96 | A-5-Y | 100<br>960 | 7.0<br>2.0 |
| On aft section of the propellant bore | A-6-X | 102<br>395<br>740 | 10.1<br>0.58<br>0.68 | A-6-Y | 102<br>800 | 7.0<br>0.8 |

* Input Control Accelerometers.

retention system were capable of withstanding the random vibration qualification test input spectrum recommended for the Mars Sample Return mission.

The sinusoidal sweep vibration qualification test and the 4-min random vibration qualification test were conducted in accordance with the vibration input spectra cited in the Martin Marietta Aerospace letter and are as follows:

Transverse Y Axis
Sinusoidal Vibration
Test Input Spectrum

| Freq. Range (Hz) | Input Level ($\pm$ G) |
|---|---|
| 10-200 | 7.5 |

(Limited to 0.5" double amplitude displacement)

Transverse Y Axis
Random Vibration
Test Input Spectra

| Freq. Range (Hz) | Input Level ($G^2/Hz$) |
|---|---|
| 20-200 | Increase at 3db/oct. |
| 200-1000 | 0.054 |
| 1000-2000 | Decrease at 6db/oct. |

(8.7 G-rms overall)

The principal results obtained from the Y-axis Sinusoidal Sweep Vibration Qualification Test and the Random Vibration Qualification are listed in Tables 3 and 5, respectively.

The last test that was conducted during the Sterilizable Motor Vibration Test Program was the Transverse Y axis Sinusoidal Sweep Vibration Qualification Test. After this test was completed, X-Y plots of all 6 accelerometer data channels were made from tape playbacks of the taped recorded data. Examination of these six X-Y plots showed an anomoly in all 6 accelerometer functions that couldn't be explained in terms of non-linear response behavior that had been observed and characterized during previous phases of this test program. The principal reason for characterizing the responses of the propellant-mounted accelerometer as an anomoly was that the decrease in resonant frequencies from about 100 Hz at the $\pm$ 1-G input level to about 57 Hz at the $\pm$ 7.5 G input was considered to be greater than was expected on the basis of non-linear behavior.

Table 5

COMPARISON OF OVERALL G-RMS RESPONSE LEVELS RECORDED DURING THE THRUST (X) AND TRANSVERSE (Y) AXIS 4 MIN/AXIS RANDOM VIBRATION QUALIFICATION TESTS OF THE STERILIZABLE MOTOR NO. 1

| | Overall (20-2000 Hz) G-RMS Response Levels | | | | |
|---|---|---|---|---|---|
| | Thrust (X) Axis Test | | Transverse (Y) Axis Test | | |
| Accelerometer Location | Accelerometer Designation | Response Level (G-RMS) | Accelerometer Designation | Response Level (G-RMS) 1st 15-sec Period | Response Level (G-RMS) last 15-sec Period |
| On test fixture adjacent to 90° motor mounting lug | A-1-X (Input Control) | 8.55 | A-1-Y (Input Control) | 8.25 | 8.55 |
| On apex of exterior surface of forward dome | A-2-X | 13.25 | A-2-Y | 42.5 | 38.25 |
| On aft dome at 90° and adjacent to nozzle boss | A-3-X | 13.75 | A-3-Y | 50.0 | 55.0 |
| On centerline of forward section of propellant bore | A-4-X | 4.7 | A-4-Y | 4.3 | 4.4 |
| On center section of propellant bore | A-5-X | 4.4 | A-5-Y | 5.2 | 5.7 |
| On aft section of propellant bore | A-6-X | 4.7 | A-6-Y | 4.4 | 4.3 |

It was suspected at this time that some of the 33 rubber propellant retention discs could have experienced damage during 4-min Y axis random vibration qualification tests that had immediately preceded the Y axis sinusoidal qualification test. In an attempt to test this hypothesis, 15-sec data samples from the 1st 15-sec period and the last 15-sec period of the 4-min Y axis random vibration test were subjected to Power Spectral Density (P.S.D.) analyses. The two sets of P.S.D. plots were compared (See Table 5) and it was concluded that no significant difference in response was evident from this data comparison. The two sets of Y-axis random P.S.D. plots were compared with the results of the Y-axis 1-G sine sweep survey test, and again no significant difference in dynamic response characteristics could be detected. It was concluded that the motor and propellant retention had not experienced any structural damage during any of the previous vibration tests, including the Y-axis random vibration, that had been conducted prior to the Y-axis Sine Sweep Vibration Qualification Test.

In an attempt to further test this hpothesis, a post-test $\pm$ 1-G sine sweep survey test was conducted along the Y-axis of the motor over a frequency range of 25-150 Hz using a logarithmic sweep rate of one octave/min. The objective of the post-test Y-axis $\pm$ 1-G sine sweep survey test was to determine if the results of this survey test would be similar to the results of the initial Y-axis $\pm$ 1-G sine survey test that was conducted on 29 July 1974. The results of the post-test and initial Y-axis $\pm$ 1-G sine sweep survey tests are summarized as follows:

| Accelerometer Designation | Accelerometer Location | Initial (29 July 74) Y Axis $\pm$ 1-G Sine Survey Test | | Post-Test (9 Aug 74) Y-Axis $\pm$ 1-G Sine Survey Test | |
|---|---|---|---|---|---|
| | | Freq.(Hz) | Level($\pm$G) | Freq.(Hz) | Level($\pm$G) |
| A-4-Y | Forward Propellant Bore | 100 | 6.25 | 42 | 2.3 |
| A-5-Y | Center Propellant Bore | 100 | 7.0 | 41 | 3.8 |
| A-6-Y | Aft Propellant Bore | 102 | 7.0 | 43 | 4.6 |

Analysis of the results presented in the above table shows large differences in the resonant frequencies and dynamic amplification factors of the $\pm$ 1-G sine survey response functions of the 3 propellant-mounted accelerometers during the initial and post-test Y-axis $\pm$ 1-G survey tests.

After the post-test Y-axis $\pm$ 1-G sine survey had been completed, the motor was subjected to a comprehensive radiographic inspection. The results of the radiographic inspection showed no evidence of structural failure of the propellant, the liner bond system, or the propellant retention system.

A rigorous explanation that would account for the large decreases in resonant frequencies and corresponding dynamic response levels that were observed during the Y-axis Sinusoidal Vibration Qualification Test of the motor cannot be offered at this time.

D. FINAL THERMAL TESTING

Since no detectable damage was incurred during the three tests described above, a more severe thermal cycle was added to the program to see if the low temperature limit could be further extended. Following the radiographic inspection at the conclusion of the vibration test, the motor was subjected to shock cooling at $-10^{o}F$ and held at that environmental temperature for 48 hours. No measurements were made during this test but X-rays taken at the end of the test with the grain still at $-10^{o}F$ revealed no separation of the bonded surfaces. The final testing was concluded on 15 September 1974 and the motor was placed in storage at $80^{o}F$.

Appendix A

WYLE LABORATORIES

TEST REPORT

19 July 1974

# TEST REPORT

WYLE LABORATORIES /Norco, California . 737-0871 , 689-2104 . TWX 910-332-1204 . Cable WYLAB

REPORT NO. 53960
OUR JOB NO. NE 53960
YOUR P. O. NO. S115883
CONTRACT --

Aerojet Solid Propulsion Company
P. O. Box 13400
Sacramento, California 95813

24 - Page Report

DATE 19 July 1974

**ACCELERATION TEST**
**ON**
**SVM-3 ROCKET MOTOR**
**PART NUMBER 1150644, SERIAL NUMBER 1**
**FOR**
**AEROJET SOLID PROPULSION COMPANY**

STATE OF CALIFORNIA } ss.
COUNTY OF RIVERSIDE }

Ray C. Myrick, being duly sworn, deposes and says: That the information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

Ray C. Myrick

SUBSCRIBED and sworn to before me this 22nd day of July, 19 74

Catherine C. Kelty

Notary Public in and for the County of Riverside, State of California

My Commission expires 14 July, 19 75

OFFICIAL SEAL
CATHERINE C. KELTY
NOTARY PUBLIC-CALIFORNIA
RIVERSIDE COUNTY
My Commission Expires July 14, 1975

W-562A

DEPARTMENT ELECTRONICS

DEPT. MGR. R. A. Wood
R. A. Wood

TEST ENGINEER N. E. Schmitz
N. E. Schmitz

TEST WITNESS

DCAS-QAR VERIFICATION

QUALITY CONTROL A. Heeseman

## TABLE OF CONTENTS

1.0 **PURPOSE**

The purpose of this report is to present the procedures used, and the results obtained in the performance of a test program. The test program was conducted to determine conformance of one SVM-3 Rocket Motor, Part No. 1150644, Serial No. 1, to the acceleration test set forth in Reference 2.1, in accordance with Reference 2.2.

2.0 **REFERENCES**

2.1 Aerojet Solid Propulsion Company Purchase Order No. S-115883, dated 14 June 1974.

2.2 Aerojet Solid Propulsion Company Test Specification No. DPT-1197-0574, "Acceleration Test Specification for SRM Propellant Grain and Grain Retention System", dated 28 May 1974.

3.0 **MANUFACTURER**

Aerojet Solid Propulsion Company
Sacramento, California

4.0 **SUMMARY**

4.1 One SVM-3 Rocket Motor was subjected to the acceleration test set forth in the referenced specification, and described in detail in this report.

4.2 Acceleration testing was performed in accordance with the requirements of the referenced specification.

4.3 There was no visible evidence of damage to the specimen as a result of the test conditions.

4.4 At the conclusion of the test, the specimen was shipped to Aerojet Solid Propulsion Company, Nimbus, California.

## 5.0 TEST CONDITIONS AND TEST EQUIPMENT

### 5.1 Ambient Conditions

5.1.1 Unless otherwise specified herein, all tests required by the specification were performed at an atmospheric pressure of 29.92 ± 1.0 inches of mercury absolute, a temperature of 70 ± 20 F, and a relative humidity of 60% or less.

### 5.2 Instrumentation and Equipment

5.2.1 Measuring and test equipment utilized in the performance of this contract have been calibrated by the Wyle Laboratories Standards Laboratory, or a commercial facility utilizing reference standards (or interim standards) whose calibration has been certified as being traceable to the National Bureau of Standards. All reference standards utilized in the above calibration system are supported by certificates, reports, or data sheets attesting to the date, accuracy, and conditions under which the results furnished were obtained. All subordinate standards, and measuring and test equipment are supported by like data when such information is essential to achieve the accuracy control required by the subject contract.

5.2.2 Wyle Laboratories attests that the commercial sources providing calibration services on the above referenced equipment, other than the National Bureau of Standards, are in fact capable of performing the required services to the satisfaction of the Wyle Laboratories Quality Control Department. Certificates and reports of all calibrations performed are retained in the Wyle Laboratories Quality Control files and are available for inspection upon request by the customer or government representative.

## 5.0 TEST CONDITIONS AND TEST EQUIPMENT

### 5.2.3 Test Equipment

| Apparatus | Manufacturer and Model No. | Description | Last Calibration Date | Wyle Number |
|---|---|---|---|---|
| **5.2.3.1 Acceleration Test** | | | | |
| Centrifuge | Wyle 0-50 rpm | 0 to 25g | System | 5348 |
| Electronic Counter | Hewlett-Packard 521CR | To 100K Hz | 4-23-74 | 30610 |
| Voltmeter | Ballantine 320 | 0 to 10vdc | 4-12-74 | 3321 |
| Digital Multimeter | Fluke 8000A | 0 to 20 vdc | 12-27-73 | 30207 |
| Power Supply | Electronic Meas. TR036-0.2 | 0 to 36 vdc | 2-5-74 | 5405 |
| Oscillograph | CEC 5-124 | 0.25 to 64"/sec 1, 10 & 100TL/sec | 4-20-74 | 51064 |
| Decade Resistor | Gen. Radio 1432N | To 10K ohm | 4-20-74 | 30063 |
| Wheatstone Bridge | Leeds & Northrup 4735 | To 10K ohm | 3-13-74 | 3325 |
| Galvanometer | Honeywell 104WIG | 0.001 ma/mm | 6-13-74 | 2343 |
| Galvanometers (4) | CEC 7-319 | 21.7 mv/in. | System calib. | 9656* 5882* 7496* 4156* |

* Serial Number

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.2.3 Test Equipment (continued)

| Apparatus | Manufacturer and Model No. | Description | Last Calibration Date | Wyle Number |
|---|---|---|---|---|
| Galvanometer | CEC 7-315 | 4.67 mv/in | System calib. | 508DT* |
| Galvanometer | CEC 7-362 | 3.23 v/in. | System calib. | 4780* |
| Temperature Recorder | Leeds & Northrup Speedomax | -100 to +300F | 4-3-74 | 31286 |

The following equipment was rented from Datacraft, Inc.

| Apparatus | Manufacturer and Model No. | Description | Last Calibration Date | Wyle Number |
|---|---|---|---|---|
| Accelerometer | CEC 4-202-001 | 0 to 25g | 6-17-74** | 6244* |
| Balance Unit | Electro Instr. B12 | 0 to 22 vdc | System calib. | -- |
| Attenuator | Electro Instr. B12-853-1B | -- | System calib. | -- |

*Serial Number

**Datacraft, Inc. Calibration Certificate is included herein as Exhibit 1, Page 24

# 6.0 REQUIREMENTS, PROCEDURES, AND RESULTS

## 6.1 Receiving Inspection

Test by: N. E. Schmitz
Performed: 11 July 1974

### 6.1.1 Performance Criteria Requirements

There shall be no visible evidence of damage to the specimen upon receipt at Wyle Laboratories. Identification information shall be complete and in conformance with the shipping documents.

### 6.1.2 Test Procedure

Upon arrival at Wyle Laboratories, and prior to any testing, the specimen was visually examined for evidence of damage which may have been incurred in shipment.

Identification information on the specimen was checked for completeness and conformance with the shipping document.

Results of the visual examination, with identification information, were recorded on the appropriate test data sheet.

### 6.1.3 Test Results

There was no visible evidence of damage to the specimen upon receipt at Wyle Laboratories.

Identification information on the shipping document designated the unit as a SVM-3 Rocket Motor, Part No. 1150644, Serial No. 1. No identification information appeared on the specimen.

The receiving inspection test data sheet is included in this report as Page 11.

## 6.0 REQUIREMENTS, PROCEDURES, AND RESULTS

### 6.2 Acceleration Test

| | |
|---|---|
| Test by: | N. E. Schmitz |
| Started: | 11 July 1974 |
| Completed: | 11 July 1974 |

### 6.2.1 Performance Criteria Requirements

Reference 2.2

The specimen shall complete the acceleration test with no visible evidence of damage.

During the acceleration test, functional parameters as described below, were recorded on a direct writing oscillograph.

### 6.2.2 Test Procedure

The rocket motor was delivered to Wyle Laboratories with four linear potentiometers attached to the propellant grain. The potentiometer mounting was accomplished by personnel of Aerojet Solid Propulsion Company (ASPC). Two of the potentiometers were mounted to record extend data and two were mounted to record retract data.

A rocket motor holding fixture, fabricated by ASPC, was attached to the centrifuge arm. An accelerometer was attached to the fixture at the center of gravity of the rocket motor. The radius of gyration, from the center of the centrifuge to the center of gravity of the rocket motor was measured to be 350.625 inches.

One galvanometer was attached to each of the four potentiometers, one galvanometer was connected to the rotational speed pickup, and one was connected to the static accelerometer. The six galvanometers were attached to a direct writing oscillograph to record the above parameters during the test.

6.0 REQUIREMENTS, PROCEDURES, AND RESULTS

6.2.2 (continued)

The four galvanometers attached to the linear potentiometers were calibrated to resistance changes equivalent to 0, 0.1, 0.2, 0.3, and 0.4 inches of deflection. The maximum sensitivity was set such that 0.4 inch deflection equalled three inches.

The galvanometer attached to the static accelerometer was shunt calibrated at levels equivalent to 4.53, 9.06, and 18.04g. The maximum sensitivity was set such that 20g acceleration was equal to two inches.

The rocket motor was then bolted to the holding fixture and the motor temperature measured at two locations just prior to starting the test. The two measurement points were the forward end and the aft end.

(Photographs 1 through 4 illustrate the test specimen mounted on the centrifuge for acceleration testing.)

The centrifuge was then started and rotated to a speed that subjected the rocket motor, at center of gravity, to an acceleration of 20 ±1 gravity units. The rotational speed of the centrifuge was increased from zero to test level, held at test level for approximately 1.5 minutes, and decreased to zero within a period of ten minutes.

During the ten-minute acceleration period, the direct writing oscillograph was operated at a paper speed of four inches per second.

Following the acceleration test, the rocket motor was removed from the holding fixture and visually examined for evidence of physical or mechanical damage.

6.0 REQUIREMENTS, PROCEDURES, AND RESULTS

6.2.3 Test Results

The rocket motor sustained no visible physical or mechanical damage.

The acceleration oscillograph recording was evaluated for maximum acceleration level and duration.

The results of the recordings of the four linear potentiometers shall be determined and evaluated by personnel of ASPC.

Results of the acceleration test are presented on the test data sheets included in this report as Pages 12 through 19.

# DATA SHEET

Customer AEROJET SOLID PROPULSION CO.

Job No. 53960

Date 7-11-74

Specimen ROCKET MOTOR

## RECEIVING INSPECTION

No. of Specimens Received: 1 ONLY

Record identification information exactly as it appears on the tag or specimen:

Manufacturer AEROJET SOLID PROPULSION

Part numbers P/N 1150644

MOD. NO. 5VM3

How does identification information appear: (name plate, tag, painted, imprinted, etc.)

UNIT NOT MARKED

Serial Numbers:* 1

Examination: Visual, for evidence of damage, poor workmanship, or other defects, and completeness of identification.

Inspection Results: There was no visible evidence of damage to the specimens unless noted below.

*If additional space is required for serial numbers, use an additional page, or reference first functional test data sheet (if applicable).

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Inspected By A BURROWS

Sheet No. ___ of ___

Approved [signature] Date 7-11-74

W614 QC Form Approval [initials]

# DATA SHEET

Test Title: ACCELERATION

Customer: AEROJET SOLID PROPULSION CO.

Part No. 1150644

S/N 1

Spec. DPT-1197-0574

Para. 4.0

Job. No. 53960

Date Test Started 7-11-74

Date Test Completed 7-11-74

Amb. Temp. NA

Photo YES

Test Med. NA

Specimen Temp. AS NOTED BELOW

Specimen ROCKET MOTOR

TEST REQUIREMENTS:

THE ROCKET MOTOR SHALL BE SUBJECTED TO A CONSTANT ACCELERATION OF 20 ± 1G FOR A MINIMUM PERIOD OF 1 MINUTE.

DURING THE ACCELERATION TEST, FUNCTIONAL PARAMETERS, AS DESCRIBED IN DETAIL BELOW WERE RECORDED ON A DIRECT WRITING OSCILLOGRAPH.

TEST PROCEDURE:

THE ROCKET MOTOR WAS DELIVERED TO WYLE LABORATORIES WITH 4 LINEAR POTENTIOMETERS ATTACHED TO THE PROPELLANT GRAIN. THE POTENTIOMER MOUNTING WAS ACCOMPLISHED BY PERSONNEL OF ASPC. TWO OF THE POTENTIOMETERS WERE MOUNTED TO RECORD EXTEND DATA AND TWO WERE MOUNTED TO RECORD RETRACT DATA.

A ROCKET MOTOR HOLDING FIXTURE, FABRICATED BY ASPC, WAS ATTACHED TO THE CENTRIFUGE ARM. AN ACCELEROMETER WAS ATTACHED TO THE FIXTURE AT THE CENTER OF GRAVITY OF THE ROCKET

Tested By A BURROWS

Specimen Meets Spec. Requirements YES ☐ NO ☐

Witness NA Date: NA

Sheet No. NA of NA

Q.C. Form Approval [signature]

Approved N. E. Johnson Date: 7-11-74

W 614 A

WYLE LABORATORIES

# DATA SHEET

Report No. 53960

Page No. 13

CUSTOMER AEROJET SOLID PROPULSION CO.

Test Title: ACCELERATION

Specimen ROCKET MOTOR | Job No. 53960

S/N —

Part No. 1150644 | Date 7-11-74

TEST PROCEDURE: (CONT.)

MOTOR. THE RADIUS OF GYRATION, FROM THE CENTER OF THE CENTRIFUGE TO THE CENTER OF GRAVITY OF THE ROCKET MOTOR WAS MEASURED TO BE 350.625 INCHES.

ONE GALVANOMETER WAS ATTACHED TO EACH OF THE 4 POTENTIOMETERS, ONE GALVANOMETER WAS CONNECTED TO THE ROTATIONAL SPEED PICKUP AND ONE GALVANOMETER WAS CONNECTED TO THE STATIC ACCELEROMETER. THE 6 GALVANOMETERS WERE ATTACHED TO A DIRECT WRITING OSCILLOGRAPH TO RECORD THE ABOVE PARAMETERS DURING THE TEST.

THE 4 GALVANOMETERS, ATTACHED TO THE LINEAR POTENTIOMETERS, WERE CALIBRATED TO RESISTANCE CHANGES EQUIVALENT TO 0, 0.1, 0.2, 0.3 AND 0.4 INCHES OF DEFLECTION. THE MAXIMUM SENSITIVITY WAS SET SUCH THAT 0.4 INCH DEFLECTION EQUALLED 3 INCHES.

THE GALVANOMETER, ATTACHED TO THE STATIC ACCELEROMETER, WAS SHUNT CALIBRATED AT LEVELS EQUIVALENT TO 4.53, 9.06 AND 18.04G. THE MAXIMUM SENSITIVITY WAS SET SUCH THAT 20G ACCELERATION WAS EQUAL TO 2 INCHES.

W 614 B

QC Form Approval

SHEET_____ OF_____

CUSTOMER AEROJET SOLID PROPULSION CO.

Test Title: ACCELERATION

Specimen ROCKET MOTOR

Part No. 1150644

Job No. 53960

S/N 1

Date 7-11-74

TEST PROCEDURE: (CONT.)

THE ROCKET MOTOR WAS THEN BOLTED TO THE HOLDING FIXTURE AND THE MOTOR TEMPERATURE MEASURED AT TWO LOCATIONS JUST PRIOR TO STARTING THE TEST. THE TWO MEASUREMENT POINTS WERE THE FORWARD END AND THE AFT END.

THE CENTRIFUGE WAS THEN STARTED AND ROTATED TO A SPEED THAT SUBJECTED THE ROCKET MOTOR, AT CENTER OF GRAVITY, TO AN ACCELERATION OF 20 ± 1 GRAVITY UNITS. THE ROTATIONAL SPEED OF THE CENTRIFUGE WAS INCREASED FROM ZERO TO TEST LEVEL, HELD AT TEST LEVEL FOR APPROXIMATELY 1.5 MINUTES AND DECREASED TO ZERO WITHIN A PERIOD OF TEN MINUTES.

DURING THE TEN MINUTE ACCELERATION PERIOD, THE DIRECT WRITING OSCILLOGRAPH WAS OPERATED AT A PAPER SPEED OF 4 INCHES PER SECOND.

FOLLOWING THE ACCELERATION TEST, THE ROCKET MOTOR WAS REMOVED FROM THE HOLDING FIXTURE AND VISUALLY EXAMINED FOR PHYSICAL OR MECHANICAL DAMAGE.

PRIOR TO AND FOLLOWING THE ACCELERATION

WYLE LABORATORIES

# DATA SHEET

Report No. 53960

Page No. 15

CUSTOMER AEROJET SOLID PROPULSION CO.

Test Title: ACCELERATION

Specimen ROCKET MOTOR

Part No. 1150644

Job No. 53960

S/N 1

Date 7-11-74

TEST PROCEDURE: (CONT.)

TEST, THE ROCKET MOTOR WAS PHOTOGRAPHED IN THE HOLDING FIXTURE ON THE CENTRIFUGE.

TEST RESULTS:

THE ROCKET MOTOR SUSTAINED NO VISIBLE PHYSICAL OR MECHANICAL DAMAGE.

THE ACCELERATION OSCILLOGRAPH RECORDING WAS EVALUATED FOR MAXIMUM ACCELERATION LEVEL AND DURATION.

THE RESULTS OF THE RECORDINGS OF THE 4 LINEAR POTENTIOMETERS SHALL BE DETERMINED AND EVALUATED BY PERSONNEL OF ASPC.

THE RESULTS OF THE ACCELERATION TEST ARE PRESENTED ON DATA SHEETS FOLLOWING THIS SECTION.

W 614 B

QC Form Approval

SHEET_____ OF_____

CUSTOMER AEROJET SOLID PROPULSION CO.
Test Title: ACCELERATION
Specimen ROCKET MOTOR
Part No. 1150644
Job No. 53960
S/N 1
Date 7-11-74

THE CONDITIONS LISTED BELOW WERE OBSERVED DURING AND FOLLOWING THE ACCELERATION TEST.

THE MAXIMUM COUNTER READING DURING THE TEST WAS 300.

THE MAXIMUM ROTATIONAL SPEED DURING THE TEST WAS 45.04 RPM.

$$RPM = \frac{\text{COUNTER READING}}{6.66}$$

THE TEST RADIUS WAS MEASURED TO BE 350.625 INCHES. MAXIMUM G LOADING WAS CALCULATED UTILIZING THE FORMULA BELOW.

$$G = C \times N^2 \times R$$

WHERE:

$G$ = GRAVITY UNITS
$C = 2.84 \times 10^{-5}$
$N$ = RPM
$R$ = RADIUS IN INCHES

THE MAXIMUM G LOADING WAS 20.2 G

THE ELAPSED TIME FROM AN ACCELERATION LEVEL OF 19G TO CENTRIFUGE SHUT OFF WAS 1 MINUTE AND 30.5 SECONDS.

THE ROCKET MOTOR SUSTAINED NO VISIBLE PHYSICAL OR MECHANICAL DAMAGE.

# DATA SHEET

CUSTOMER AEROJET SOLID PROPULSION CO.

Test Title: ACCELERATION

Specimen ROCKET MOTOR

Part No. 1150644

Job No. 53960

S/N 7

Date 7-11-74

JUST PRIOR TO THE START OF THE TEST, THE TEMPERATURES LISTED BELOW WERE MEASURED.

FORWARD END: 91°F

AFT END: 88°F

TESTED BY: A BURROWS

APPROVED: N.E. Schmitz

**WYLE LABORATORIES**

SPECIMEN: ROCKET MOTOR
CUSTOMER: AEROJET SOLID PROP.
PART NO.: 1150644
S/N: 1
TEST: ACCELERATION

JOB NO.: 53960
DATE: 7-11-74
TEST BY: A BURROWS
WITNESS: Na

| EQUIPMENT | MANUFACTURER | MODEL NO. | RANGE | WYLE NO. | CALIBRATION LAST | CALIBRATION DUE | ACCY. |
|---|---|---|---|---|---|---|---|
| CENTRIFUGE | WYLE | 0-50 RPM | 0-25G | 5348 | SYSTEM | | SYSTEM |
| ELECTRONIC COUNTER | H.P. | 521CR | TO 100K HZ | 30610 | 4-23-74 | 8-25-74 | ±1 count |
| VOLTMETER | BALLANTINE | 320 | 0 TO 10 VDC | 3321 | 4-12-74 | 8-11-74 | ±3% |
| DIGITAL MULTIMETER | FLUKE | 8000A | 0 TO 20 VDC | 30207 | 12-27-73 | 12-29-74 | ±.1% |
| POWER Supply | ELECTRONIC MEASUREMENTS | TR 036-02 | 0 TO 36 VDC | 5405 | 2-5-74 | 8-18-74 | N/A |
| OSCILLOGRAPH | CEC | 5-124 | .25 TO 64"/SEC 1,10,100 TL/SEC | 51064 | 4-20-74 | 8-18-74 | ±2% TL |
| DECADE RESISTOR | GR | 1432N | TO 10KΩ | 30063 | 4-20-74 | 10-20-74 | *** |
| WHEATSTONE BRIDGE | L&N | 4735 | TO 10KΩ | 3325 | 3-13-74 | 9-13-74 | ±.05% |
| ACCELEROMETER | CEC | 4-202-001 | 0 TO 25G | *S/N 6244 | 6-17-74 | NEXT USE | ** |
| BALANCE UNIT | EI | B12 | 0 TO 22 VDC | * | SYSTEM | | Na |
| ATTENUATOR | EI | B12-853-1B | N/A | * | SYSTEM | | Na |
| GALVO | Honeywell | 104W1G | .001 ma/mm | 2343 | 6-13-74 | 12-15-74 | N/A |
| GALVANOMETER | CEC | 7-319 | 21.7 MV/IN | S/N 9656 | SYSTEM CAL. | | Na |
| GALVANOMETER | CEC | 7-319 | 21.7 MV/IN | S/N 5882 | SYSTEM CAL | | Na |
| GALVANOMETER | CEC | 7-319 | 21.7 MV/IN | S/N 7496 | SYSTEM CAL. | | Na |
| GALVANOMETER | CEC | 7-319 | 21.7 MV/IN | S/N 4156 | SYSTEM CAL. | | Na |
| GALVANOMETER | CEC | 7-315 | 4.67 MV/IN | S/N 5080T | SYSTEM CAL | | Na |

W 614 C    Q.C. Approval [illegible]

SHEET    OF

WYLE LABORATORIES

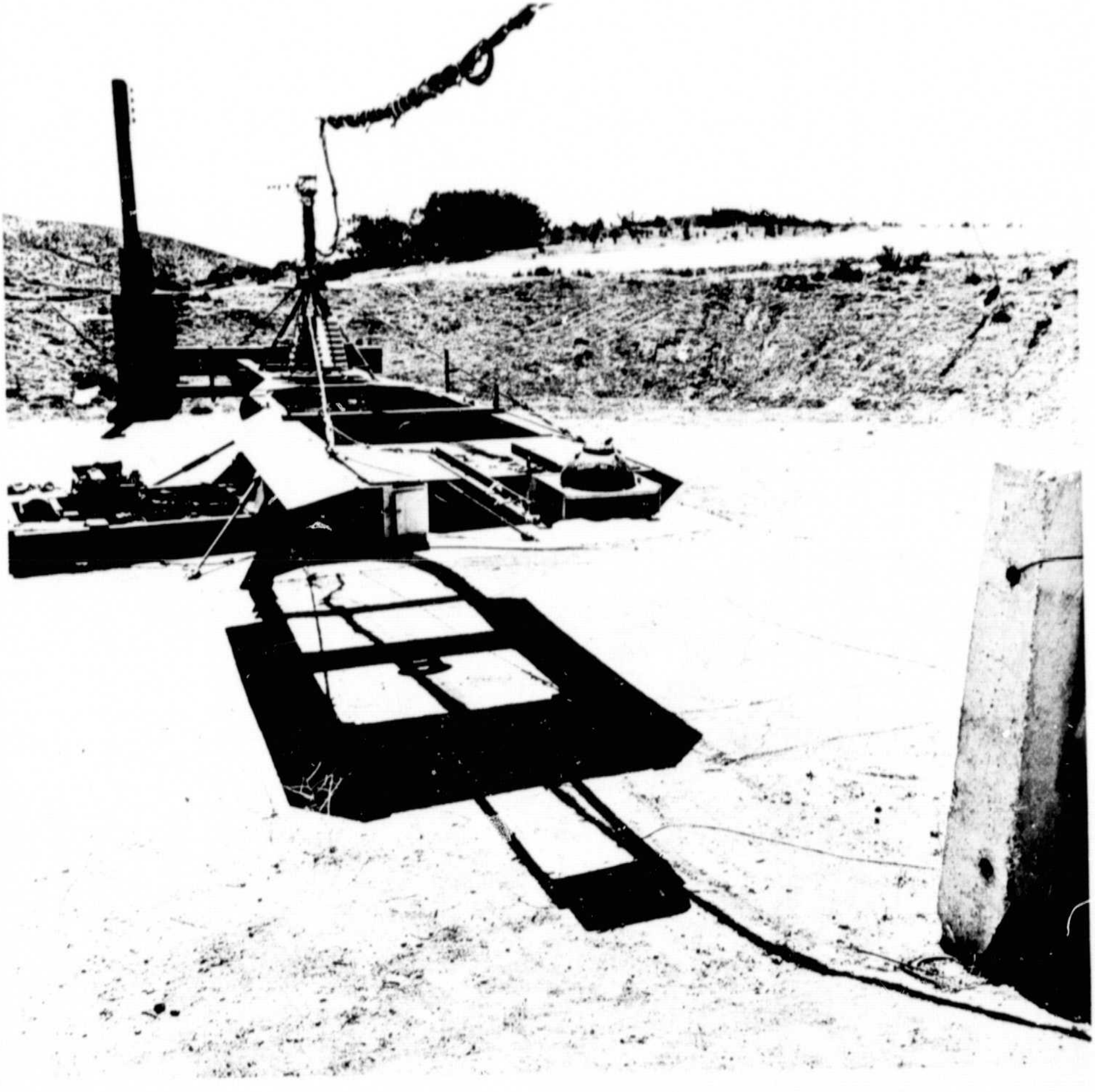
SPECIMEN ROCKET MOTOR
CUSTOMER AEROJET SOLID PROP.
PART NO. 1150644
S/N 1
TEST: ACCELERATION

JOB NO. 53960
DATE 7-11-74
TEST BY A BURROWS
WITNESS [illegible]

| EQUIPMENT | MANUFACTURER | MODEL NO. | RANGE | WYLE NO. | CALIBRATION LAST | CALIBRATION DUE | ACCY. |
|---|---|---|---|---|---|---|---|
| GALVANOMETER | CEC | 7-362 | 3.23 V/IN | S/N 4780 | SYSTEM CAL | | [illegible] |
| TEMPERATURE RECORDER | LEEDS & NORTHRUP | SPEEDOMAX | -100 TO +300°F | 31286 | 4-3-74 | 8-4-74 | ±.5% FS |
| * RENTAL EQUIPMENT FROM DATACRAFT, INC. | | | | | | | |
| ** 0.16% LINEARITY & 0.16% HYSTERESIS | | | | | | | |
| *** 0.1 OHM DECADE, 0.5% | | | | | | | |
| 1.0 OHM DECADE, 0.15% | | | | | | | |
| 10 OHM DECADE, 0.05% | | | | | | | |
| ALL OTHER DECADES, 0.025% | | | | | | | |

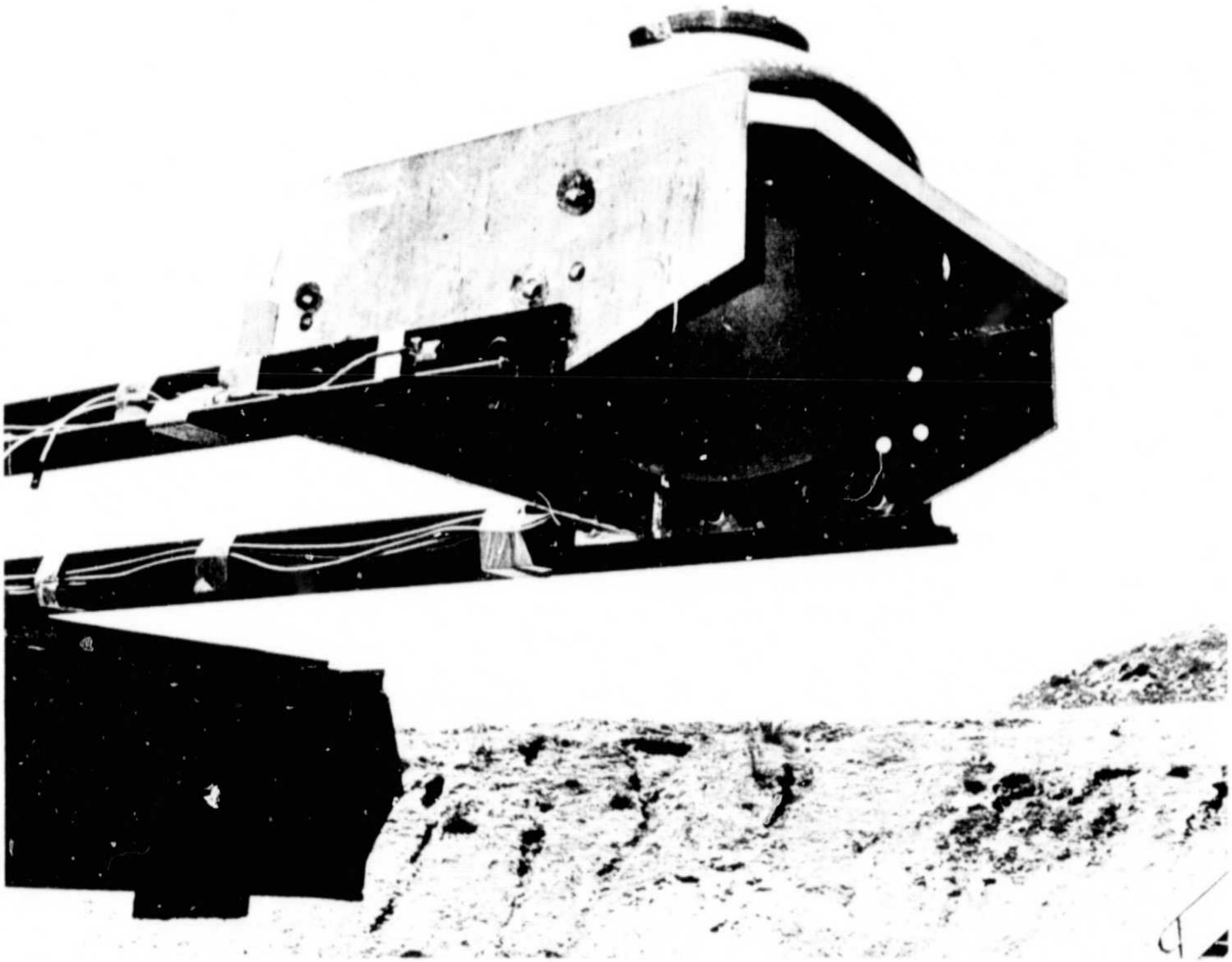
W 614 C Q.C. Approval [illegible]

SHEET OF



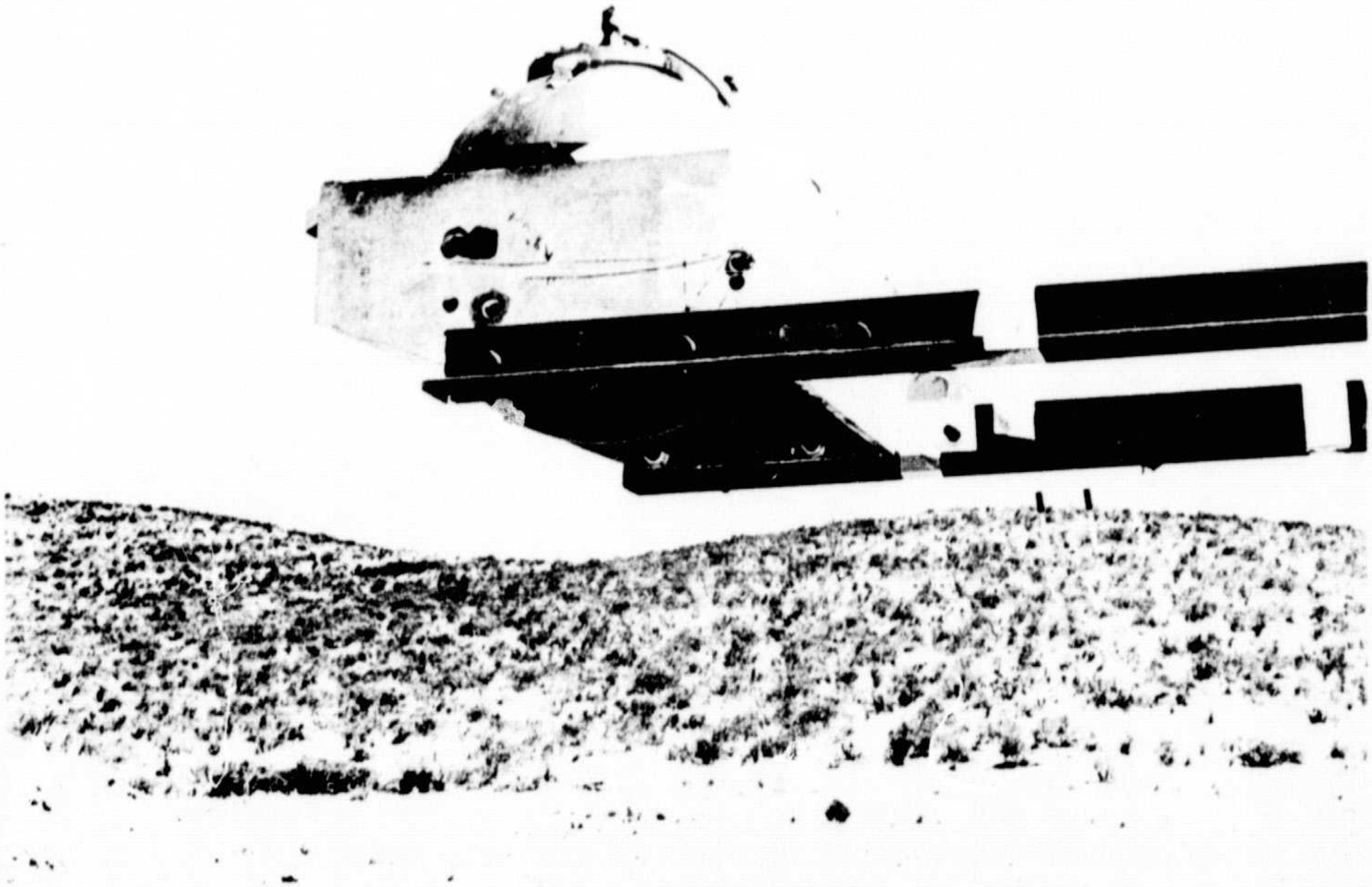
PHOTOGRAPH 1

SVM-3 ROCKET MOTOR
ACCELERATION TEST SETUP
(Pre-Test)



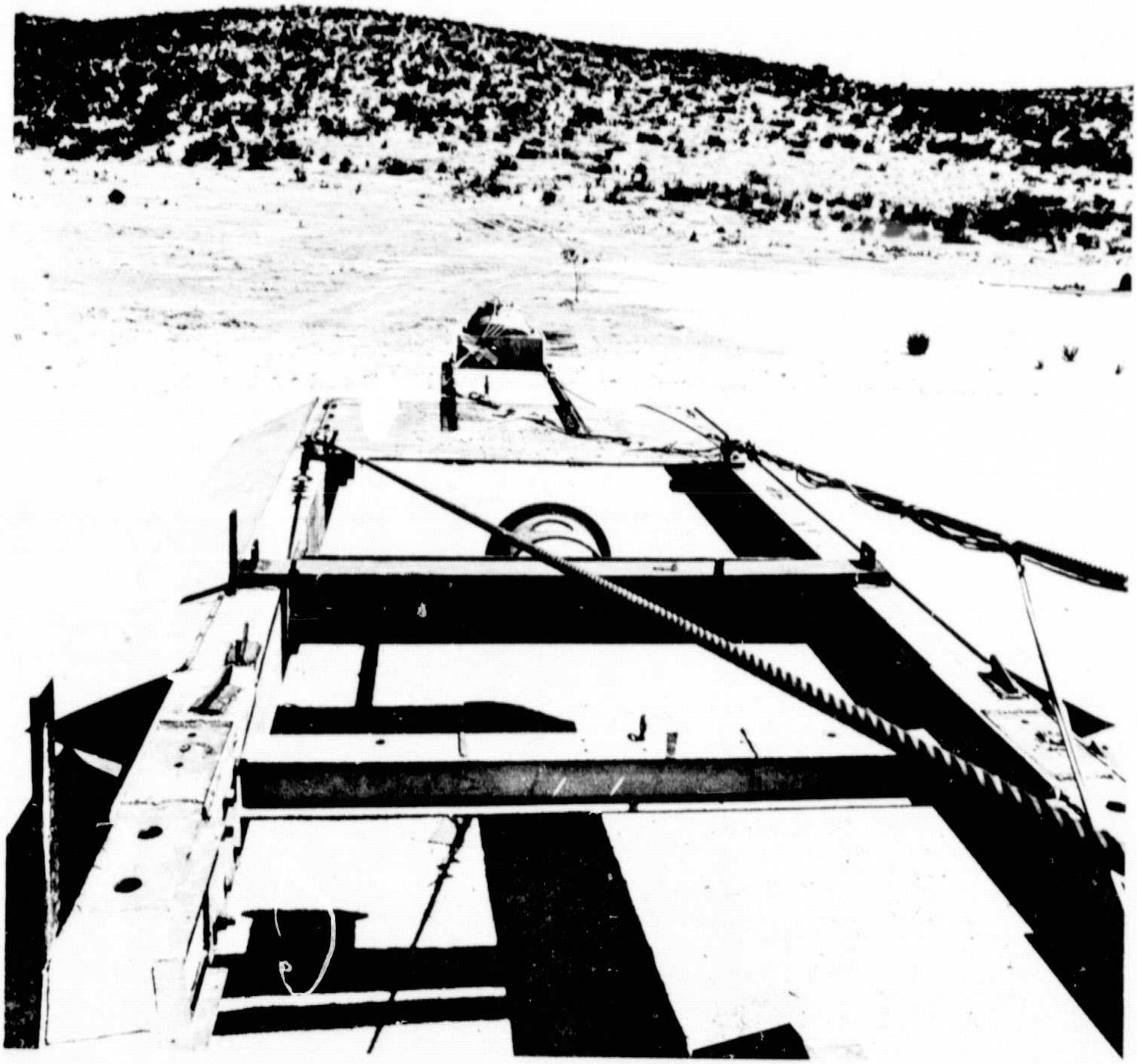
PHOTOGRAPH 2

SVM-3 ROCKET MOTOR
ACCELERATION TEST SETUP
(Pre-Test)



PHOTOGRAPH 3

SVM-3 ROCKET MOTOR
ACCELERATION TEST SETUP
(Pre-Test)



PHOTOGRAPH 4

SVM-3 ROCKET MOTOR
ACCELERATION TEST SETUP
(Post Test)

EXHIBIT 1

DATACRAFT, INC.

INSTRUMENTATION

# TRANSDUCER CALIBRATION

Model No H-200-0001 Serial No. 6244

Range 0-±25G Manufacturer CEC

Max. Excitation Voltage 5.0V DC AC

Input Terminals # 1&4 (A&B) Resistance 350Ω

Output Terminals # 2&3 (B&C) Resistance 350Ω

SENSITIVITY:

Millivolts 23.82 Excitation 5VDC Applied Load +25.0G

LINEARITY & HYSTERESIS: Temperature 73°F

| Units | Millivolts (Up) | Millivolts (Down) |
|---|---|---|
| 0 | 0 | 0 |
| 5 | 4.80 | 4.83 |
| 10 | 9.54 | 9.58 |
| 15 | 14.30 | 14.34 |
| 20 | 19.07 | 19.12 |
| 25 | 23.82 | |

Linearity .16%

Hysteresis .16%

PSID:

Millivolt Shift —

At Line Pressure of —

CALIBRATION FACTOR:

| Resistance | Millivolts | Units |
|---|---|---|
| 250K | 1.23 | 1.82 |
| 120K | 2.55 | 2.67 |
| 100K | 4.32 | 4.53 |
| 50K | 8.63 | 9.06 |
| 25K | 17.19 | 18.04 |

Tested by Ken Shearer Jr. Approved by Robert Rauch

Date 6-17-74

## Appendix B

# VIBRATION TEST PLAN

# FOR THE

# STERILIZABLE SOLID ROCKET MOTOR

13 May 1974



Prepared by;

T. E. Depkovich
Sr. Engineering Specialist
Dynamics 4350

TABLE OF CONTENTS

## I. INTRODUCTION

This test plan describes the vibration test setups, accelerometer instrumentation plans, and test procedures that will be used in conducting the sinusoidal and random vibration tests of one sterilizable solid rocket motor in accordance with the test requirements specified in Article 1, Exhibit "A", of JPL Contract No. 953848.

The test motor will consist of an unfired SVM-3 titanium motor case in which the live ANB-3438 propellant and SD-886 liner are structurally attached to the insulated motor case by means of a 33-disc rubber propellant retention system.

The test motor will not contain a nozzle or igniters. The design details of the SVM-3 motor case and propellant grain configuration are shown in ASPC Drawing No. 1150644. The design details of the 33-disc rubber propellant retention system are shown in ASPC Drawing No. 1150643. The sterilizable motor is unique and different from all the previously tested ASPC space vehicle motors (SVM-1 through SVM-6) because of the rubber propellant retention system. The propellant retention system is incorporated into the design of the motor to enable the motor to withstand a sterilization temperature of 275°F without inducing thermal failure stresses in the propellant-liner-case bond system.

For this reason, emphasis in this motor vibration test program will be directed towards obtaining sinusoidal and random vibration input and response measurements of the motor case and propellant that could be used to characterize the dynamic response behavior of the propellant retention system. The resonant frequencies, dynamic amplification factors, and corresponding mode shapes of the motor case and propellant obtained from the 1-G Sine Survey Tests will be evaluated with respect to the results of the pre-test propellant and propellant retention system stress analysis.

I, Introduction (cont.)

The failure limits associated with sinusoidal and random vibration test conditions will be established and a set of sinusoidal and random vibration test input spectra that would give the motor a 50/50 chance of survival when subjected to the selected sinusoidal and random vibration test conditions will be determined.

If the vibration test input spectra that would give the motor a 50/50 chance of survival are excessively more severe than the vibration test input spectra that are generally specified for vibration tests of similar type of Apogee kick motors (SVM-1 through SVM-6), a set of realistic sinusoidal and random vibration test input spectra will be selected for the sterilizable motor vibration test program that represent the maximum vibration input environments that are associated with the launch/boost phase of a space vehicle.

The objectives of the JPL sterilization motor vibration test program are:

A. To determine the resonant frequencies, dynamic amplification factors of the motor and establish the dynamic response behavior of the propellant retention system.

B. To evaluate the results of the motor vibration tests with respect to the pre-test motor stress analysis and determine the vibration test conditions that would induce motor failure.

C. To determine a set of sinusoidal and random vibration test input spectra that would give the motor a 50/50 chance of survival when subjected to the selected vibration test environments.

I, Introduction (cont.)

D. To conduct the motor vibration test using sinusoidal and random vibration test input spectra that would give the motor a 50/50 chance of survival, or if this test is unrealistically severe, conduct the vibration tests of the motor using a less severe vibration test input environment that represents a realistic and reasonable overtest condition of the motor.

The SVM-3 Titanium motor case, the rigid magnesium test support fixture, and the magnesium transverse axis drive and attach tooling have been used successfully during the 1969-1970 sinusoidal and random vibration testing of a series of SVM-3 development and qualification test motors. The SVM-3 test fixtures and drive/attach tooling were designed and fabricated by Kimball Industries, Inc., Covina, Calif., to be compatible with the Ling Model A-249 electrodynamic exciter.

The 1-G Sine Survey tests will be completed in each of the two motor test axes prior to the initiation of any full-level sinusoidal or random vibration endurance testing. This procedure is considered necessary to ensure that the fundamental frequency and modal response characteristics of the motor and propellant are obtained in each motor test axis during this program for an applied low-level 1-G constant sinusoidal acceleration input level.

All vibration testing of the sterilizable motor will be conducted at ambient temperatures. The responses of all attached accelerometers will be continuously recorded on a magnetic tape recorded throughout each sine survey, sine endurance, and random vibration endurance test.

Comprehensive radiographic inspections of the test motor will be conducted prior to the start of, and at the completion of, the vibration test program.

The test motor will not be static fired at the completion of the vibration test program.

## II. VIBRATION TEST SETUPS

### A. GENERAL

The sterilizable motor is spherical in shape, weighs about 152 lb, and has a diameter of 18 in.

The motor case is made from 6Al4V titanium and the case thicknes: varies from 0.031-0.036-in. except in the thickened regions of the equators and the bosses where the case thickness reaches a maximum of 0.045-in.

The test motor will not contain a nozzle or igniters during this test program.

Live ANB-3438 propellant and the SD-886 liner will be attached to the insulated motor case by means of a 33-disc rubber propellant retention system.

The motor will be bolted to the rigid magnesium test fixture at its three motor mounting lugs and will be maintained in a vertical, "nozzle up" during both the thrust (x) and transverse y axis testing. See Figures 1 and 2.

The motor case and propellant grain configuration are described in ASPC Drawing No. 1150644 and the propellant grain configuration is described in ASPC Drawing No. 1150643.

B. THRUST (X) AXIS VIBRATION TEST SETUP

The sterilizable motor will be bolted to the split steel ring at the top surface of the magnesium test support fixture through the three motor mounting lugs as shown in Figure 1. Design details of the magnesium test support fixture and the split steel ring are described in ASPC Drawing No. E-1104189.

The base of the magnesium test fixture containing the test motor will be bolted directly to the upper surface of the moving element of the Ling Model A-249 electrodynamic exciter as shown in Figure 1.

The specified x (thrust) axis sine and random vibration input spectra will be applied by the electrodynamic exciter to the base of the magnesium test support fixture along an axis parallel to the thrust axis of the motor.

The following tabulation is a weights summary of the thrust (x) axis test configuration:

| Component | Weight (lb) |
|---|---|
| Motor | 152 |
| Magnesium Test Fixture | 330 |
| Split Steel Fixture Motor Mounting Ring | 30 |
| Ling A-249 Exciter Moving Element | 400 |
| | 912 |

## C. TRANSVERSE Y (90°-270°) AXIS VIBRATION TEST SETUP

The test motor will be bolted in a "nozzle up" vertical attitude to the split steel ring at the top of the magnesium test support fixture through the three motor mounting lugs. A 3/4-in. thick magnesium slip plate will be bolted to the base of the magnesium test support fixture. The base of the magnesium slip plate will be placed on the oil film surface of the vibration slip table.

The exciter system will be rotated 90° about its trunnion axis and the Kimball Industries, Inc., magnesium driver bar (P/N 6014) will be bolted at its base to the moving element of the Ling Model A-249 electrodynamic exciter. The structural attachment of the magnesium test support fixture to the magnesium driver bar will be made through the magnesium tool plate (ASPC Drawing No. E-1104189). A schematic view of the transverse y (90°-270°) test setup is shown in Figure 2.

The following tabulation is a weight summary of the transverse y (90°-270°) axis test configuration:

| Component | Weight (lb) |
|---|---|
| Motor | 152 |
| Split Steel Ring | 30 |
| Magnesium Test Fixture | 330 |
| Magnesium Driver Bar | 170 |
| Magnesium Drive Plate | 42 |
| Magnesium Slip Plate | 60 |
| Exciter Moving Element | 400 |
| | 1184 |

The specified transverse y axis sine and random vibration input spectra will be applied by the electrodynamic exciter to the magnesium test support fixture along an axis parallel to the 90°-270° motor axis.

## III. VIBRATION TEST INSTRUMENTATION

### A. THRUST (X) AXIS INSTRUMENTATION

Six crystal accelerometers having flat frequency response characteristics over a frequency range of 5 to 2000 Hz will be mounted on the test support fixture, the motor case, and the propellant bore as shown in Figure 1.

The specific locations and orientations of the six x (thrust) axis accelerometers are described in the following table:

ACCELEROMETER INSTRUMENTATION PLAN
STERILIZABLE SOLID ROCKET MOTOR
X (THRUST) AXIS INSTRUMENTATION

| Accelerometer Designation | Accelerometer Location |
|---|---|
| A-1-X (Input Control) | On the top surface of the split steel ring that is bolted to the magnesium test fixture and immediately adjacent +0 the motor mounting lug at 90°. |
| A-2-X | On the apex of the exterior surface of the motor forward dome. |
| A-3-X | On the motor aft dome at 90° and adjacent to the nozzle boss. Accelerometer A-3-X will be mounted so that its sensitive axis will be parallel to the thrust (x) axis of the motor. |
| A-4-X | On the centerline of the propellant bore at a distance of 12.48" from the aft surface of the nozzle boss. |
| A-5-X | On the propellant bore at 90° and 7.49" from the aft surface of the nozzle boss. |
| A-6-X | On the propellant bore at 90° and 2.70" from the aft surface of the nozzle boss. |

B. TRANSVERSE Y (90°-270°) AXIS INSTRUMENTATION

Six crystal accelerometers having flat frequency response characteristics over a frequency range of 5-2000 Hz will be mounted on the test support fixture, the motor case, and on the propellant bore as shown in Figure 2.

The specific locations and orientations of the six transverse y axis accelerometers are described in the following table:

ACCELEROMETER INSTRUMENTATION PLAN
STERILIZABLE SOLID ROCKET MOTOR
TRANSVERSE Y (90°-270°) AXIS INSTRUMENTATION

| Accelerometer Designation | Accelerometer Location |
|---|---|
| A-1-Y (Input Control) | On the top surface of the split steel ring that is bolted to the magnesium test fixture and mounted adjacent to the motor mounting lug at 90°. |
| A-2-Y | One the apex of the external surface of the motor forward dome. |
| A-3-Y | On the motor aft dome at 90° and adjacent to the nozzle boss. Accelerometer A-3-Y will be mounted so that its sensitive axis is parallel to the transverse y (90°-270°) axis of the motor. |
| A-4-Y | On the centerline of the propellant bore at a distance of 12.48" from the aft surface of the nozzle boss. |
| A-5-Y | On the propellant bore at 90° and 7.49" from the aft surface of the nozzle boss. |
| A-6-Y | On the propellant bore at 90° and 2.70" from the aft surface of the nozzle boss. |

## IV. VIBRATION TEST PROCEDURES

### A. GENERAL

This vibration test program differs from conventional vibration qualification test programs from the standpoint that the sinusoidal and random vibration endurance test input spectra are not specified in the Exhibit "A" Statement of Work of JPL Contract No. 953848.

One objective of this vibration test program is to determine a set of sinusoidal and random vibration test conditions that would give the motor a 50/50 chance of survival when subjected to the selected test environments. In the event that the vibration test environment that would give the motor a 50/50 chance of survival is excessively and unrealistically more severe than vibration test environments that are generally specified for similar types of Apogee Kick motor, a set of realistic sinusoidal and random vibration test conditions will be selected for the motor test program that represent a realistic and reasonable overtest condition.

The sinusoidal and random vibration test environments that will be considered for possible application to the JPL sterilizable motor will be derived from those that have been applied to the ASPC SVM-1 through SVM-6 space vehicle motors during past solid rocket motor vibration test programs.

The vibration test environments that have been applied during the past 10 years to the various ASPC Apogee Kick motors represent the sinusoidal and random vibration environments that are imposed at the structural interface between the Apogee Kick motors and the Spacecraft during launch of a Communications Satellite and other types of space surveillance vehicles.

The vibration and shock test environments that have been specified for the previously completed Apogee Kick motor test programs are of short durations that are generally less than four minutes/motor test axis.

The final selection of the thrust and transverse axis sine and random vibration endurance test input spectra will be made after the 1-G Sine Survey tests have been completed on each motor test axis. This selection will be based on the results of 1-G Sine Survey tests and the pre-test motor stress analysis.

The vibration test sequences and procedures that will be used to accomplish the objectives of this vibration test program are described in the following sections of this test plan.

## B. VIBRATION TEST SEQUENCE

The following types of vibration tests will be performed on the test motor in the following listed test sequence:

1. Transverse y (90°-270°) Axis 1-G Sine Survey Test
2. Thrust (x) Axis 1-G Sine Survey Test
3. Thrust (x) Axis Sinusoidal Sweep Vibration Endurance Test
4. Thrust (x) Axis Random Vibration Endurance Test
5. Transverse y (90°-270°) Sinusoidal Sweep Vibration Endurance Test
6. Transverse y (90°-270°) Random Vibration Endurance Test

C. 1-G SINE SURVEY VIBRATION TEST PROCEDURES

Each sine sweep survey test will consist of one sine sweep up from 10-2000 HZ at a constant 1-g (zero-to-peak) input acceleration level using a logarithmic sweep rate of two octaves/min.

The applied ± 1.0g input level will be controlled and monitored at the input control accelerometer A-1-X during the X-axis sine sweep survey test and at input control accelerometer A-1-Y during the Y-axis sine sweep survey test.

The output signal of the input control accelerometer will be displayed on an oscilloscope during the 1-G sine survey test and the amplitude and wave form of the input control signal will be monitored throughout each 1-G Sine Survey Test.

The responses of all six accelerometers will be continuously recorded on a magnetic tape recorder throughout each 1-G Sine Survey Test.

After each sine survey test has been completed, all six channels of acceleration response data recorded during each sine survey test will be played back through a 20-Hz bandwidth tracking filter onto an x-y plotter.

The six acceleration versus frequency x-y plots will be analyzed by the "on-site" ASPC Dynamics Engineer and the frequency response data obtained from the 6 x-y plots will be evaluated with respect to the results of the pre-test motor and propellant retention system stress analysis. Failure limits of the propellant or the 33-disc propellant retention system with respect to both sinusoidal and random vibration input spectra will be established.

A sinusoidal sweep vibration endurance test input spectrum and a random vibration endurance test input spectrum that will give the motor a 50/50 chance of survival, or a less severe test environment that constitutes a reasonable over-test condition will then be specified for each of the two motor test axes.

## D. SINUSOIDAL SWEEP VIBRATION ENDURANCE TEST PROCEDURE

Based upon past ASPC vibration test experience with 6 previously completed Apogee Kick motor vibration test programs, and knowledge of typical sinusoidal vibration environments generated during the launch phase of a space vehicle, a sinusoidal sweep vibration endurance test will be selected for each motor test axis.

The sinusoidal sweep vibration endurance test for each motor test axis will consist of one sweep up from 10-2000 Hz using a logarithmic sweep rate of two octaves/min. The establishment of the maximum acceleration input levels and the shape of input spectrum to be applied to each motor test axis will be specified prior to the start of each sinusoidal sweep vibration endurance test.

The test procedures to be used during each sinusoidal sweep vibration endurance test are identical to those described above for the 1-G Sine Survey tests.

The response of the six accelerometers will be continuously recorded on a magnetic tape recorder during each sinusoidal sweep vibration endurance test.

The time required to sweep from 10 to 2000 Hz at a logarithmic sweep rate of two octaves/min. is 3.82 min.

Filtered (20 Hz bandwidth tracking filter) x-y acceleration-versus-frequency x-y plots of the responses of the 6 attached accelerometers will be made from tape playbacks of the accelerometer data that were recorded during the sinusoidal weep vibration test. The 6 x-y plots will be analyzed by the "on-site" ASPC Dynamic Engineer and the acceleration-frequency response data obtained from the 6 x-y plots will be compared with corresponding x-y plots obtained from the 1-G Sine Survey tests. These data will be evaluated with respect to the pre-test motor stress analysis results and the specified random vibration endurance test input spectrum. Final selection of the random vibration endurance test input spectrum will be made after this evaluation has been completed.

## E. RANDOM VIBRATION ENDURANCE TEST PROCEDURES

The following random vibration tests will be conducted over a test frequency range of 20-2000 Hz in the following test sequence:

1. "Closed Loop" equalization checkout using the specified random vibration endurance test input spectrum.

2. Low-level (10 db down) equalization test.

3. A 15-sec full-level random vibration test using the specified random vibration endurance test input spectrum.

4. A full-level random vibration endurance test of 1.75-min. test duration.

The specified random vibration input spectra will be controlled and monitored at input control accelerometer A-1-X during the x (thrust)

axis random vibration tests and at input control accelerometer A-1-Y during the transverse y-axis random vibration tests.

The responses of 6 accelerometers will be continously recorded on a magnetic tape recorder during the low-level equalization, the 15 sec full level random, and 1.75-min. full level random vibration tests.

Power spectral density analyses (50 Hz or narrower analyzer filter bandwidth) will be made for all 6 channels of random response data recorded in each motor test axis. The overall g-rms level will be determined for each data channel analyzed and the numerical value of the overall g-rms level will be entered on each PSD plot.

## F. VIBRATION TEST TOLERANCES

### 1. Sinusoidal Vibration Tests

The sinusoidal vibration input amplitudes shall be with ± 10% of specified input levels.

All vibration frequencies shall be within ± 2%, or ± 1/2 Hz below 20 Hz.

### 2. Random Vibration Tests

The specified random vibration input spectra shall be within ± 3 db over the test range of 20-2000 Hz.

The applied overall g-rms level of the specified random vibration input spectra shall be within ± 10% of the specified overall g-rms level.

The on-line, contiguous filter of the equalization/analysis system shall have a filter bandwidth of 50 Hz, maximum.

## V. VIBRATION DATA REQUIREMENTS

The number of x-y (acceleration versus frequency) plots and P.S.D. (Power Spectral Density versus Frequency) plots required at the completion of this vibration test program are:

| Test Type | No. of x-y Plots Required | No. of PSD Plots Required |
|---|---|---|
| y-Axis 1-G Survey Test | 6 | |
| x-Axis 1-G Survey Test | 6 | |
| x-Axis Sine Endurance Test | 6 | |
| x-Axis Random Endurance Test | | 6 |
| y-Axis Sine Endurance Test | | 6 |
| y-Axis Random Endurance Test | | 6 |
| Total | 18 | 18 |

## VI. PHOTOGRAPHIC REQUIREMENTS

Still photographs will be taken to show the following:

A. Overall views of the test setup used in conducting the vibration tests in the thrust and one transverse axes of the motor.

B. Close-up views of all externally mounted accelerometers.

C. If damage or structural failure occurs, close-up views of the damaged or failed parts will be taken.

A minimum of four views will be taken for each test set-up. Three glossy prints, size 8-1/2 x 11" of each photograph will be provided, complete with identification, date, and caption.

X (THRUST) AXIS VIBRATION, TEST SETUP AND ACCELEROMETER INSTRUMENTATION PLAN STERILIZABLE SOLID ROCKET MOTOR

10 May 1974

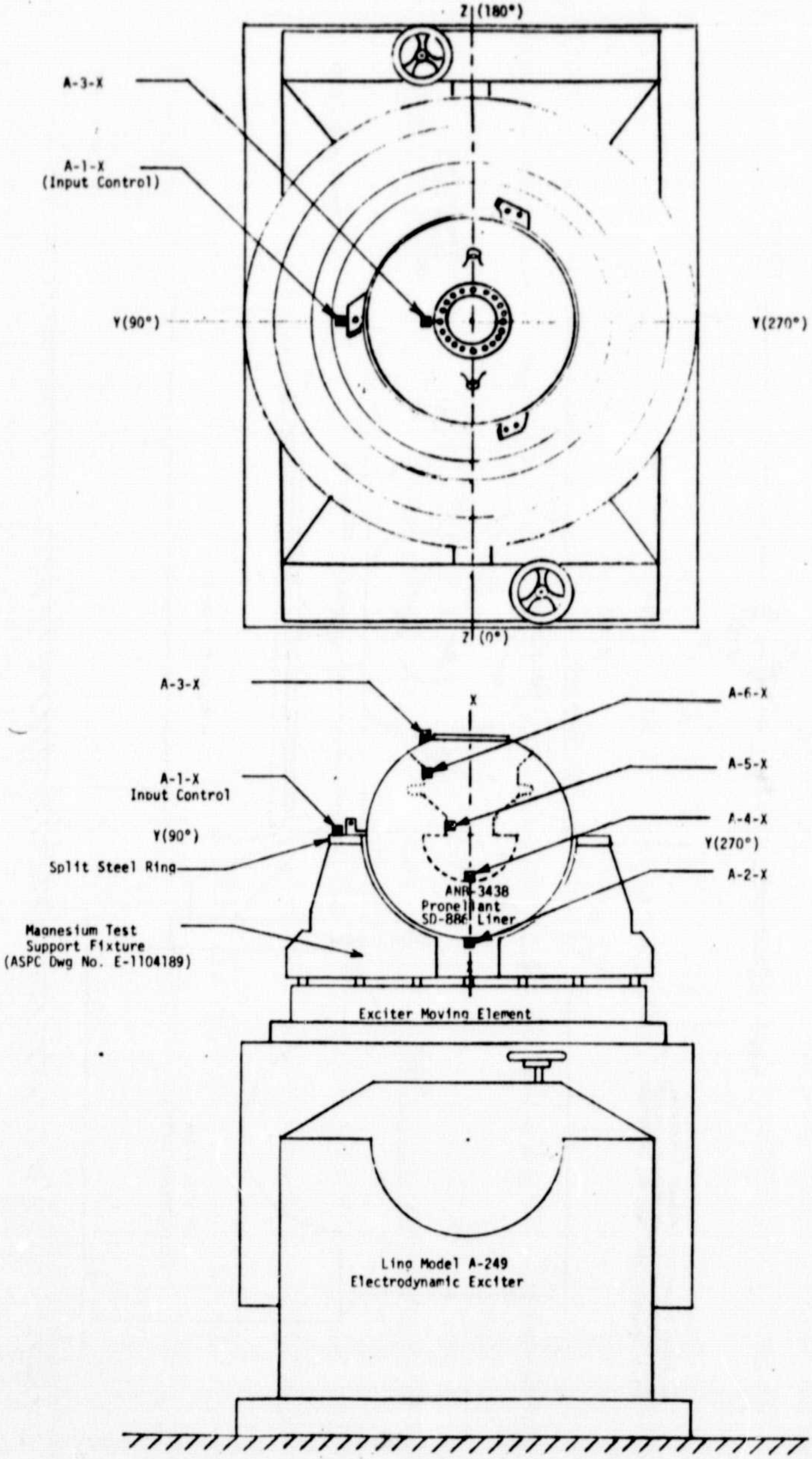



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Figure 1

TRANSVERSE Y (90°-270°) X
VIBRATION TEST SET UP AND
ACCELEROMETER INSTRUMENTATION PLAN

STERILIZABLE SOLID ROCKET MOTOR

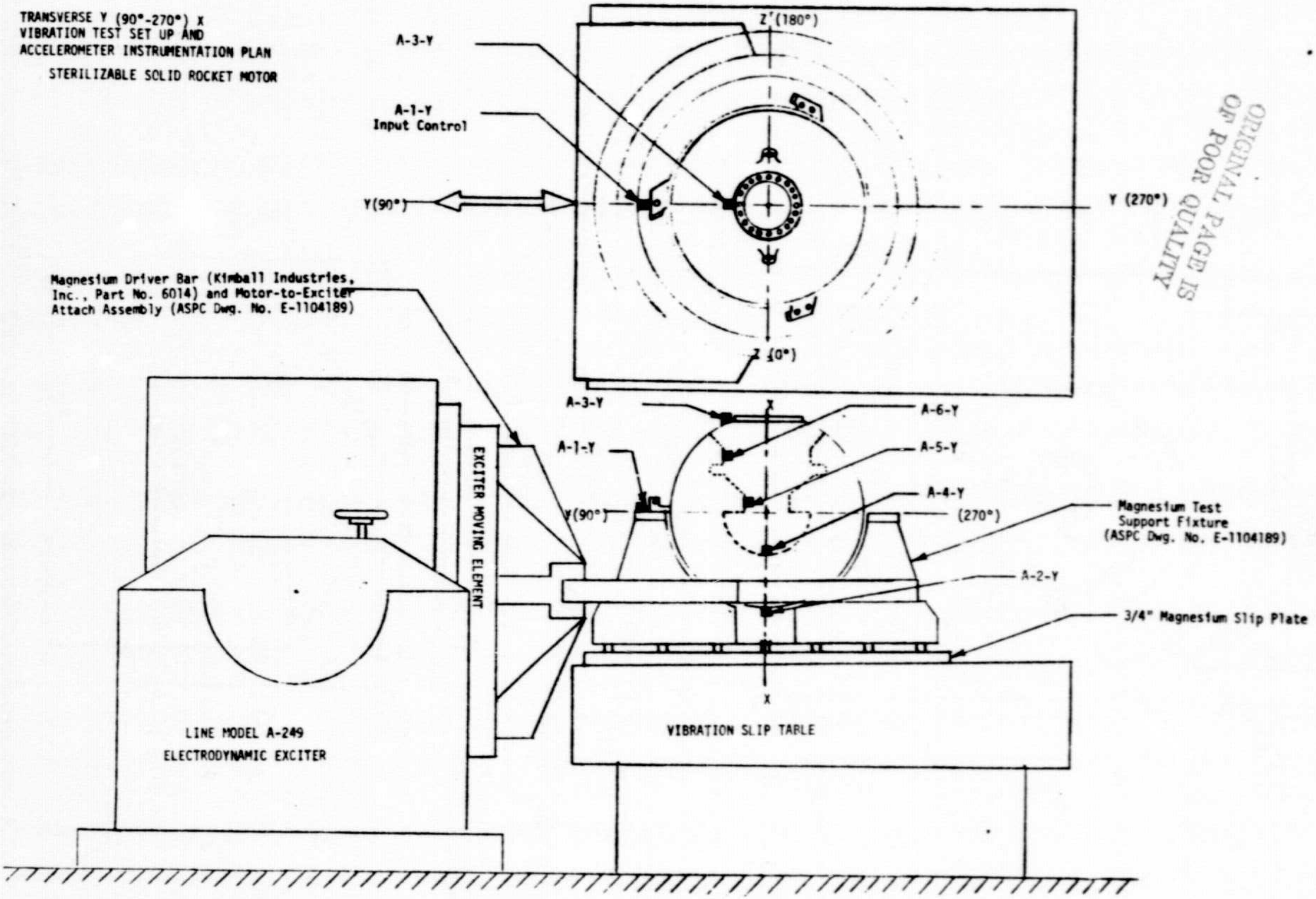




Figure 2